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GROVES AND THORP'S

CHEMICAL TECHNOLOGY

OR

CHEMISTRY

APPLIED TO ARTS AND MANUFACTURES

VOL. I.

FUEL

CHEMICAL TECHNOLOGY

OR

CHEMISTRY IN ITS APPLICATIONS TO ARTS AND MANUFACTURES

EDITED BY

CHARLES EDWARD GROVES, F.R.S.

EDITOR OF THE JOURNAL OF THE CHEMICAL SOCIETY

AND

WILLIAM THORP, B.Sc.

WITH WHICH IS INCORPORATED

RICHARDSON AND WATTS' CHEMICAL TECHNOLOGY

VOL. I.

FUEL AND ITS APPLICATIONS

BY

E. J. MILLS, D.Sc., F.R.S., AND F. J. ROWAN, C.E.

(EDITED BY CHARLES E. GROVES)

WITH

SEVEN PLATES AND 607 OTHER ILLUSTRATIONS

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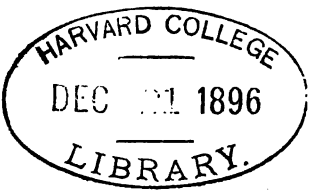

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PREFACE.

THIS volume is the first of a new edition of "Chemical Technology," founded on that written by Richardson and Ronalds, and subsequently much enlarged and in great part rewritten by Richardson and Watts. As the German Technology of Dr. Knapp was taken as the basis of the original, Richardson and Watts' work has long been familiarly known as "Knapp's Technology."

The law of progress, to which all industrial processes are subject, however, causes any work on Technology to become out of date in a few years, and this applies in a special manner to the very large class of operations which are closely connected with Chemistry. For nowhere has the extraordinary activity in all departments of knowledge which has been witnessed during the last thirty years been more marked than in the domain of Chemistry, and this has necessarily borne fruit, not only in the modification of old methods, but also in the invention of new processes, and in the introduction of more perfect methods of research.

On this account it has been deemed advisable to issue a new edition of this Technology, or, rather, a new work on Chemical Technology, in which the historical portions of the original have been retained, but supplemented by a full account of the most approved and successful methods and appliances introduced of late years in the application of Chemistry to the Arts. This work will be divided into sections, of which the most important are—

FUEL AND ITS APPLICATIONS.	TEXTILE FABRICS.
LIGHTING.	LEATHER, PAPER, &C.
ACIDS AND ALKALIES.	COLOURING MATTERS AND DYES.
GLASS AND POTTERY.	OILS AND VARNISHES.
METALLURGY.	BREWING AND DISTILLING.

SUGAR, STARCH, FLOUR, &C.

The present volume treats of Fuel and its Applications generally; its special employment in various branches of chemical manufacture being reserved for detailed consideration in the volumes devoted to the special subjects enumerated above.

The questions connected with the constitution and use of fuel form no

exception to the general course of advancement, and there is no doubt that both the nature of combustion and also the economical distribution and utilization of heat are more clearly apprehended by many than they were formerly. In fact, the progress in this department has been such that this volume, although founded on the earlier one, is really a new work, and this remark will necessarily apply also to the volumes on Lighting, &c., which will follow. Where possible, historical matter from the old edition has been retained, especially on account of its great value in the case of processes or appliances which are capable of being made the subjects of patents. It is not too much to say that many patents owe their existence to ignorance concerning what has been done in the matters of which they treat; and manufacturers would often find historical information of great use if it were available without laborious searching through Patent Office records.

The subjects of the manufacture of gas for illumination, methods of lighting by oil and gas, the manufacture of candles, the distillation of coal, shale, wood, and peat, with the secondary products obtained therefrom, miners' safety-lamps, and other lamps used for lighting, have been excluded from this volume, which is consequently restricted to the consideration of Fuel and its Applications.

Where possible the duty obtained from the fuel in furnaces has been quoted, and general rules have been given by which the duty of any stated furnace or heating appliance may be estimated. In the case, however, of furnaces used for some special process—as, for instance, chemical furnaces—it is not easy to obtain this information, as their duty is generally expressed in terms of the chemical product which they turn out, and the thermal elements of the chemical processes other than combustion which are carried out in them must in these cases be taken into account. Particulars of these instances must therefore be looked for in the volumes dealing with the chemical manufactures in which such furnaces are employed. What Sir I. Lowthian Bell has done in this respect for the process of making pig-iron remains, however, to a great extent to be done by others in the case of other industries.

In the Preface to the former (1856) edition, the Author stated that a method of smoke prevention, although much wanted, had not then been discovered. That cannot be said now, for not only has the idea of "consuming smoke" become obsolete, but also the requirements of complete combustion are so well understood that only through carelessness need the bulk of industrial firing with solid fuel be other than practically smokeless. The use of gaseous fuel, moreover, is well known to be a perfect method of smoke prevention, which even carelessness in manipulation cannot vitiate to a serious extent. Exhibitions of appliances for preventing smoke which have been held of recent years in Glasgow, Manchester, and London have done much to popularize the use of suitable methods.

The figures representing the output of coal in Britain and other

countries show the enormous development which has taken place in the fuel industry all over the world. At the same time it is creditable to the skill of mining experts that the larger volume of mining work is (in this country, and presumably in others also) conducted with a greatly lessened percentage of accidents.

The labours of the Royal Commission on Accidents in Mines in this country, and of Mining Commissions in France and Germany, have within the last few years thrown needed light on several matters connected with coal-mining, and especially on the part played by coal-dust in explosions in mines, and this will necessarily result in further improvement in the methods of working coal.

On the continent of Europe, methods of cleaning, washing, and classifying coal have reached a great degree of elaboration and refinement, and these methods are gradually affecting the practice in Britain, in spite of the smaller monetary value of coal per ton in this country.

In the manufacture of coke, there has been great development of methods of coking, by which the waste gases are collected for the extraction of their ammonia, tar, &c. The gases from blast furnaces using coal and from gas-producers have also been made to yield these products, and great advance has likewise been made in the perfection of methods of extracting ammonia in shale distillation. The nature of coke has also been made the subject of close examination by several chemists and metallurgists—in particular by Sir I. Lowthian Bell in this country, and by Mr. F. P. Dewey in America, the latter of whom has furnished valuable contributions to this volume.

Undoubtedly the greatest development in the application of fuel which has taken place since 1856, however, is to be found in the spread of the use of the gaseous form of fuel, and in the introduction of appliances for its use in manufacturing and in domestic operations.

Regenerative furnaces—and especially that of Siemens—have introduced a new era in methods of firing and heating on an industrial scale, and have been a powerful means of spreading intelligent knowledge in the use of fuel, which has produced marked effects in domestic heating and lighting operations also. Methods of producing gas for various purposes, as well as appliances for utilizing it in different operations, have consequently become numerous. Attention has been turned to the forms of furnaces, the nature of flame, the transmission of heat, the calorific value of fuels, and many kindred points, with an activity previously unknown, and it will easily be understood that the mass of information which has thus been acquired is far too great for the limits of any one work. It is hoped that this volume has succeeded in presenting such a view of the subject as will be valuable generally, and, from the copious references given, specialists will be enabled to study in detail the particular branches with which they are concerned.

Besides well-known technical institutions, many friends of the Authors have placed valuable information at their disposal, amongst whom may

be mentioned the Institution of Civil Engineers, the Iron and Steel Institute, the Institute of Mechanical Engineers, and the Mining Institute of Scotland, by special permission of their respective Councils; Dr. Bond, Mr. J. Constantine, Mr. E. A. Cowper, Messrs. Crosby Lockwood & Co., Mr. T. Fletcher, Mr. J. Mactear, Messrs. Massicks & Co., Mr. Henry Simon, Messrs. Verity & Co., Mr. W. Whitwell, Messrs. Wright & Co., and others, to all of whom the Authors and Editor desire to tender their sincere thanks.

August 1889.

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CHEMICAL TECHNOLOGY.

FUEL.

THE BRANCHES OF MANUFACTURE CONNECTED WITH THE PRODUCTION OF FUEL AND THE PROCESS OF COMBUSTION.

EVERY person who has directed his attention to the necessary conditions for carrying on any branch of manufacturing industry, will be well aware that heat and the effects produced by its agency, take precedence of all others. It is almost impossible to mention any manufacture in which either an elevated temperature or the power obtained by means of that temperature, is not employed in some way or other. Even in agriculture, steam power is being gradually introduced for performing those operations in which manual labour has hitherto been employed; small steam engines are now used on many farms of consequence in England and Scotland, the number of which will no doubt increase with a knowledge of scientific principles and with the necessity for saving labour in that all-important art, so that in a few years the application and utilization of artificial heat will probably be as much the rule in agriculture as in the economical production of cotton fabrics, iron, or any of the chemical or metallurgical products of the world. Most of these manufactures, however, are entirely dependent on the agency of heat, and, generally speaking, of an intense heat, so that it is of importance to every one connected with the arts, to acquire a knowledge of the sources of heat, and the chemical and physical laws concerned in its production; without this it is impossible to apply this invaluable agent in the manner best suited to the object in view and with the greatest amount of profit and economy.

Every substance which is capable of burning in the air, that is, of combining with oxygen with the evolution of light and heat, might be employed as a heating agent, but of the numerous combustible substances which nature supplies, few are found in quantity sufficient to be generally applicable to the production of artificial heat. These few, however, are so abundant, and so generally diffused, that no inhabited country is entirely devoid of one or other of them; indeed, so essential is artificial heat, in some form or other, to human existence, that no country totally without the means of producing it, would be habitable to any extent for any length of time.

The wealth of this country, derived as it is chiefly from her success in manufactures, depends in a great measure on the abundant supply of one of the richest sources of artificial heat lying buried in the earth, in her coal-

fields. Great Britain had but small influence in the councils of Europe until these were discovered and turned to full account by the indomitable industry and enterprise of her inhabitants; and without so invaluable an accessory to the acquirement of wealth and power, her commercial fate and fame might soon have sunk to a level with those of the most insignificant State in Europe.

FUEL.

The substances to which allusion has been made above, and which we collectively call *Fuel*, are: wood; peat or turf; brown-coal or lignite; pit-coal or coal; wood-charcoal; peat-charcoal; coke from brown-coal and coal; certain combustible gases; cereals and refuse vegetable matter; some liquid hydrocarbons; and artificial fuel. All these substances are more or less closely allied to wood or woody fibre, from which they seem to have originally been mainly derived, and all are indebted for their combustible properties to the carbon and hydrogen of which they are essentially composed.

These two elements, together with oxygen and small quantities of nitrogen, sulphur, phosphorus, water, and inorganic salts (ash), compose the entire mass of the natural fuels; their relative value as fuel depending in a great measure on the proportions in which the two former elements enter into their composition.

Most artificial fuels contain carbon as the essential ingredient; the other constituents, with the exception of the ash, having been expelled in the processes of manufacture.

The value of fuel is diminished by the ash, which is not combustible; and the sulphur and phosphorus sometimes present are peculiarly prejudicial in some of its applications.

The facility with which fuel is ignited and continues to burn, depends to a great extent on its chemical constitution and on the porosity of its texture. A large amount of hydrogen is generally favourable to rapid ignition; this element, in combination with a portion of the carbon, separates, as carburetted hydrogen, at a temperature below redness, and the combustible gas thus produced burns and heats the remainder of the fuel, causing the combustion to spread. The portion of carbon which is not burnt in the form of gaseous hydrocarbons, is left by the escape of the gas in such a porous state, that the atmospheric oxygen easily obtains access, and the whole is consumed.

The property of burning with flame is thus intimately connected with the presence of hydrogen in the combustible, and the artificial fuels which contain no hydrogen, only produce flame when the quantity of air directly supplied to them is insufficient for the production of carbonic acid, or when the carbonic acid formed passes through a layer of glowing carbon; carbonic oxide is then produced, which may again be ignited in contact with more air. Steam may be used instead of air, or a mixture of steam and air may be employed in the production of carbonic oxide mixed with hydrogen.

Wood, peat, and some kinds of brown and gas coals produce the longest flame; they contain the largest amount of hydrogen, and are most easily decomposed. Coal generally is not so inflammable, and some varieties, as anthracite, burn without flame, like charcoal and the other artificial fuels. These distinctions are important in many applications of fuel. Where the materials to be heated are separated from the combustible, an inflammable fuel must be selected, the greatest heat being then found at the extremity of the flame. On the other hand, great local intensity of heat is obtained, so to speak, in immediate contact with those kinds of fuel which are consumed without flame.

WOOD.

The trunk, roots, and larger branches of trees are all called *wood*. The other parts, leaves, twigs, and small branches, called *brushwood*, are likewise

used as fuel, and differ from the more solid portions in the proportions of the several constituents to be mentioned hereafter, and in the inflammability and heating power which they exhibit; but as these form a very small proportion of the wood employed as fuel, it is unnecessary to specify these differences more minutely than is done in the subsequent tables, showing the elementary composition and amount of ash in some of the more important.

Wood is composed of three different substances: first, *woody fibre*, $C_6H_{10}O_5$, which forms the cells and vessels of the plant, and makes up the chief part of its bulk; second, the *constituents of the sap* contained in the vessels; and last, *water*. The most important of the sap constituents is a soluble gum (lignin), amounting on the average to 13 per cent. of the wood, and having the same elementary composition as cellulose itself. Recently felled wood necessarily contains all three constituents. The two first are combustible, and produce heat; the water, on the contrary, whilst the wood is burning, is converted into vapour at the expense of a portion of this heat. As woody fibre and water are common to all kinds of wood, the difference which has been shown to exist between different woods must depend entirely on the constituents of their sap, and on their structure (density). Notwithstanding the great difference, chemically speaking, in the constituents of the sap (the coniferous woods containing resinous matter; the beech and birch, extractive; and the oak, tannin), the accurate analysis of dried woods has shown that they contain the three elementary constituents, *carbon*, *hydrogen*, and *oxygen*, nearly in the same proportions as pure woody fibre does. The constituents of the sap, therefore, can form but a very small proportion of the whole bulk of the wood, or else they have the same composition; and their action cannot materially alter the value of the wood as fuel, although it becomes very perceptible when the wood is applied to certain practical purposes, as in the process of tanning. The amount of water in wood has greater influence, and is of much more importance, as it materially influences its calorific power. Water is generally most abundant in wood at the time of the flow of the sap, and least, when the growth is less rapid; for which reason, wood should always be felled at the latter stage, unless the important secondary uses for which it is sometimes cultivated, as the tannin in the bark, &c., render it desirable to fell it at an earlier stage of growth. The amount of water (sap) in wood differs according to the time of year at which it is felled. Thus, Schübler and Neuffer found:—

Water per cent.

Woods.	At the end of January.	At the beginning of April.
Ash	28.8	38.6
Sycamore	33.6	40.3
Horse-chestnut	40.2	47.1
White Fir	52.7	61.0

It is also greater in the young shoots and twigs than in the more solid stem, and varies also in amount in woods of a like nature but of different botanical species, as the following table (given also by Schübler and Neuffer) shows:—

100 Parts of fresh cut Wood from the

	Water.		Water.
Hornbeam (*Carpinus betulus*) contain	18.6	Pine (*Pinus sylvestris L.*) contain	39.7
Willow (*Salix caprea*)	26.0	Red Beech (*Fagus sylvatica*)	39.7
Sycamore (*Acer pseudoplatanus*)	27.0	Alder (*Betula alnus*)	41.6
Mountain Ash (*Sorbus aucuparia*)	28.3	Aspen (*Populus tremula*)	43.7
Ash (*Fraxinus excelsior*)	28.7	Elm (*Ulmus campestris*)	44.5
Birch (*Betula alba*)	30.8	Red Fir (*Pinus picea, Dur.*)	45.2
Wild service tree (*Crataegus tormin.*)	32.3	Lime Tree (*Tilia europea*)	47.1
Oak (*Quercus robur*)	34.7	Italian Poplar (*Populus italica*)	48.2
Pedicle Oak (*Quercus pedunculata*)	35.4	Larch (*Pinus larix*)	48.6
White Fir (*Pinus abies, Dur.*)	37.1	White Poplar (*Populus alba*)	50.6
Horse-chestnut (*Aesculus hippocast.*)	38.2	Black Poplar (*Populus nigra*)	51 8

Chevandier examined the hygroscopic state of the wood of the beech, oak, white beech, birch, aspen, alder, willow, fir, and pine, from different parts of the same tree and at intervals of six months, one year, one and a half, and two years, after the trees had been felled. The numerous specimens upon which he experimented, amounting to 181 in number, were taken from trees of various ages, grown upon different soils, and the specimens were exposed to the free access of air in an open shed, protected, however, from the rain and the direct action of the sun's rays. The amount of moisture in each was determined at the different intervals by drying weighed quantities, in the form of sawdust, at a temperature of 140° C. (284° F.) in a vacuum, until they ceased to lose weight.

From these experiments, it appeared that the soil and site upon which the trees grew had no appreciable influence on the amount of moisture contained in or retained by the wood.

The minimum of hygrometric water in the woods, or the maximum state of dryness, was attained for the greater number after the lapse of a year and a half; the others required two years to be brought to the same state.

The resinous woods dry more rapidly, but likewise absorb moisture with greater avidity, than those which contain no resin; and among the latter, the softer kinds (birch, aspen, alder, willow) contain more water in the fresh state than the harder woods; they lose this water, however, with greater ease, and can be more thoroughly dried.

The following are the mean of the results obtained in the experiments:—

1. Mean quantity of Hygrometric Water contained in the Resinous Woods.

Trunk-wood	half a year after felling	29 per cent.
Brushwood	" " "	32 "
Young branch-wood	" " "	38 "
Trunk-wood	in the driest state	15 "
Brushwood	" " "	15 "
Young branch-wood	" " "	15 "

2. Mean quantity of Hygrometric Water contained in the Non-Resinous Woods.

Trunk-wood	half a year after felling	26 per cent.
Brushwood	" " "	34 "
Young branch-wood	" " "	36 "
Trunk-wood	in the driest state	17 "
Brushwood	" " "	20 "
Young branch-wood	" " "	19 "

These numbers must be considered as minima, single specimens being more perfectly dried than wood stacked and not freely exposed to the air.

In recently felled wood, therefore, from $\frac{1}{5}$ to $\frac{1}{2}$ of its weight is water, and in that commonly used for fuel about $\frac{1}{3}$. This quantity is very much diminished by keeping the wood dry and exposed to the air, but it is not entirely removed under any circumstances. After the expiration of one and a half or two years, when the wood is in the driest state to which it can be brought by exposure, the hygroscopic properties of the air and the wood appear to be in a state of equilibrium and to balance each other, the amount of water in the latter varying within narrow limits with the season of the year and with the hygrometric state of the atmosphere at the time of observation. In this state of dryness, in which wood is best adapted for use as fuel, the wood is said to be *air dried*. The remaining moisture can only be expelled with the aid of heat, and the last portions with such difficulty that the wood commences at the same time to decompose, and becomes brown.

Violette heated wood, which had been seasoned for two years, for two hours in a current of super-heated steam, at 125°–225° C. (257°–437° F.). The loss of water is given below :—

Temp. C.	Water expelled from 100 parts of				Temp. F.
	Oak.	Ash.	Elm.	Walnut.	
125°	15.26	14.78	15.32	15.55	257°
150°	17.93	16.19	17.02	17.43	302°
175°	32.13	21.22	—	21.00	347°
200°	35.80	27.51	33.38	—	392°
225°	44.31	33.38	40.56	36.56	437°

Between 200° C. (392° F.) and 225° C. (437° F.) there was slight carbonization, and water alone was not given off.

Rumford heated the following air-dried woods at a temperature of 136° C. (277° F.) as long as they lost weight without being chemically changed, and found that 100 parts of

Oak-wood lost	16.64	Fir-wood lost	17.53
Elm ,,	18.20	Birch ,,	19.38
Beech ,,	18.56	Lime ,,	18.79
Maple ,,	18.63	Poplar ,,	19.55*

For practical purposes, such a complete state of dryness can seldom be attained, and the wood used for fuel, after exposure to the air for ten or twelve months, contains from 20 to 25 per cent. of water. The former number taken as the mean, reduces 100 lbs. of air-dried wood to only 80 lbs. of real fuel. Wood, several years old, which had been kept in a warm room for six months, still retained about 17 per cent. of water (Winkler).†

The following table, from Wagner's Technology, gives the average time in which woods used for fuel are fit for felling :—

Wood.	Years.	Wood.	Years.
Oak	50—60	Birch	20—25
Red Beech	80—120	White Fir	50—60
White Beech	110—120	Red Fir	70—80
Elm	20—30	Common Fir	80—100
Ash	20—30	Larch	50—60
Alder	20—30		

Wood is commonly divided into the *hard* and *soft* kinds, a distinction grounded on the facility with which it is worked, and on its power of producing heat. The former class, embracing the wood of the oak, white and red beech, birch, elm, and alder, contains in an equal bulk more solid fibre, and the vessels are narrower and more closely packed than in that of the softer kind, which includes the wood of the pine, fir, white fir, larch, lime, willow, and poplar. High situations, much exposed to wind, and a poor soil, cause the annual rings to be less developed, and consequently more closely packed, than is the case with wood which is protected and grows on the more fruitful soil of valleys. The specific gravity of wood must necessarily stand in a certain relation to its hardness, and increase with the latter, and this being a point of some practical importance, several experimenters

* The same kinds of wood, freed in like manner from water at a temperature of 136° C. (277° F.) and exposed in shavings to the air, absorbed in winter (at 45° F.) from 17 to 19 per cent. and in summer (at 62° F.) from 6 to 9 per cent. of water within 24 hours, which facts easily explain why wood is dried with so much difficulty.

† The wood composing the beam of a room 150 years old and preserved from moisture, had a sp. gr. of 0.682 and contained 10.5 per cent. water.

have turned their attention to the subject. The specific gravity of wood, which is the sum of the weight of the solid matter with that of the water contained in it, and of the air of the pores,* cannot be ascertained with that degree of accuracy to which we are accustomed in scientific investigations, as these different constituents occur in variable proportions.

The difficulty of arriving at a knowledge of the true specific gravity of wood has been very much increased by the different, and often inaccurate, modes of experimenting which have been adopted for determining this point. Wood, supposing it free from pores containing air, is sensibly heavier than water. Thus, after destroying the pores by rasping and determining the volume of the raspings, the specific gravity of lime-wood was found to be 1.13, of fir-wood 1.16, of oak-wood 1.27, of beech-wood 1.29. Rumford's experiments led to the conclusion that the solid part of all woods without distinction had a specific gravity of about 1.5, and experience has shown that wood sinks after long immersion in water, when the air has been expelled from it.

The specific gravity of wood has been observed to vary in the same variety with the age of the specimen, the nature of the soil upon which it has been grown, the climate, &c.; it is not even the same in different parts of the same tree. Young wood is specifically heavier than old, and heart-wood bears a like relation to sap-wood.

In the following table, the respective weights of the different kinds of wood, in the state in which they are used as fuel, are given according to the best authorities.

SPECIFIC GRAVITY OF DIFFERENT KINDS OF WOOD; WATER BEING UNITY.

Variety of Wood.	I. Recently felled.	II. Dried in air.	III. Strongly dried.	IV. Strongly dried.	V.
Common Oak (*Quercus robur*)	1.0754	0.7075	0.6441	0.663	0.929
Pedicle Oak (*Quercus pedunculata*)	1.0494	0.6777	—	0.663	—
White Willow (*Salix alba*)	0.9859	0.4873	0.4464	0.457	0.585
Beech (*Fagus sylvatica*)	0.9822	0.5907	0.5422	0.560	0.852
Elm (*Ulmus campestris*)	0.9476	0.5474	0.5788	0.518	0.600
Hornbeam (*Carpinus betulus*)	0.9452	0.7695	—	0.691	—
Larch (*Pinus larix*)	0.9205	0.4735	—	0.441	—
Scotch Fir (*Pinus sylvestris*)	0.9121	0.5502	0.4205	0.485	—
Sycamore (*Acer pseudoplatanus*)	0.9036	0.6592	0 5779	0.618	0.755
Ash (*Fraxinus excelsior*)	0.9036	0.6440	0.6137	0.619	0.734
Birch (*Betula alba*)	0.9012	0.6274	0.5699	0.598	—
Mountain Ash (*Sorbus aucuparia*)	0.8993	0.6440	—	0.552	—
Fir (*Pinus abies, Duroi*)	0.8941	0.5550	0.4303	0.493	0.550
Silver Fir (*Pinus picea, Dur.*)	0.8699	0.4716	0.3838	0.434	—
Wild service (*Cratægus torminalis*)	0.8633	0.5910	—	0.549	0.874
Horse-chestnut (*Aesculus hippoc.*)	0.8614	0.5749	—	—	—
Alder (*Betula alnus*)	0.8571	0.5001	—	0.443	0.800
Lime (*Tilia europœa*)	0.8170	0.4390	0.3480	0.431	0.604
Black Poplar (*Populus nigra*)	0.7795	0.3656	—	0.346	0.383
Aspen (*Populus tremula*)	0.7654	0.4302	—	0.418	—
Italian Poplar (*Populus italica*)	0.7634	0.3931	0.4402	—	—
Ground Willow (*Salix caprea*)	0.7155	0.5289	—	0.501	—
Guaiacum Wood	Grif-	1.3420	—	—	—
Ebony	fith	1.2260	—	—	—

* Thus Rumford calculated from the sp. gr. of the fresh wood of sappy trees, and from that of its solid parts, that 1 cub. ft. of fresh oak-wood contained 390 cub. in. of solid fibre, 360 cub. in. of sap, and 240 cub. in. of enclosed air. Poplar-wood in the same state contains in the cubic foot, 243 cub. in. of fibre, 219 cub. in. of sap, and 538 cub. in. of air; lime-wood, 265 cub. in. of wood, 365 cub. in. of sap, and 370 cub. in. of air. According to another calculation, 1 cub. ft. of air-dried lime-wood contains 558 cub. in. of air in the pores; fir-wood, 586 cub. in.; oak-wood, 481 cub. in.; and beech-wood, 457 ub. in.

The columns I. and II. contain the weights ascertained by Hartig; and column III. the less accurate determination of Wernek. The specimens of wood employed by the latter were dried in an oven, until they ceased to lose weight, and the loss which they sustained, on being immersed in water, was then determined. In column IV., the results obtained by Winkler are given, who weighed an exact cubic inch of each wood. The specimens had been kept for six months in a strongly heated chamber, and the water they contained had been thus reduced to an average of about 9 per cent. Column V. contains Mushenbroek's numbers. A very extensive list of the relative weights of the woods from different countries will be found in the Reports of the Juries of the Exhibition of 1851.

The following determinations of the specific gravity of woods were made by Karmarsh.

Names of Woods.	SPECIFIC GRAVITY.				Mean weight of 1 cub. foot of air-dried Wood in lbs.*
	In the green state.		In the air-dried state		
	Limits.	Mean.	Limits.	Mean.	
Maple	0.843—0.944	0.893	0.645—0.750	0.697	37 lbs.
Apple	0.960—1.137	1.048	0.734—0.793	0.763	41 ,,
Birch	0.851—0.987	0.919	0.688—0.738	0 713	38 ,,
Pear	. . .	. .	0.646—0.732	0.689	37 ,,
Red Beech	0.852—1.109	0.980	0.690—0.852	0.771	41 ,,
Box	. . .	. .	0.912—1.031	0.971	52 ,,
Cedar	. . .	. .	0.561—0.575	0.568	30 ,,
Ebony	. . .	. .	1.187—1.331	1.259	67 ,,
Oak	0.885—1.052	0.973	0.650—0.920	0.785	42 ,,
Alder	0.809—0.994	0.901	0 505—0.680	0.592	31 ,,
Ash	0.778—0.927	0.852	0.540—0.845	0.692	37 ,,
Pine	0.848—0.993	0 920	0.454—0.481	0·467	25 ,,
Scotch Fir	0.811—1 005	0.908			
Larch	0.694—0.924	0.809	0.565	0.565	30 ,,
Lime	0.710—0.878	0.794	0.559—0.604	0.581	31 ,,
Poplar	0.758—0.956	0.857	0.383—0.591	0.487	26 ,,
Guaiac	. . .	. .	1.263—1.342	1.302	69 ,,
Silver Fir	0.894	0.894	0.498—0.746	0.622	33 ,,
Elm	0.878—0.941	0.909	0.568—0.671	0.619	35 ,,
Willow	0.838 -0.855	0.846	0.392—0.530	0.461	25 ,,
White Beech	0.939 —1.137	1.038	0.728—0.790	0.759	40 ,,

Most trustworthy results, obtained by the method of immersion, have been recorded by Marcus Bull, who took the precaution of covering each specimen with a varnish of sp. gr. = 1.000, which, without giving rise to error, ensured the presence of the whole natural quantity of air in the wood. The most important of his experiments are given in the table below; they apply only to foreign woods.

Walnut (with scaly bark)	1.000	Virginian Cherry	0.597
White Oak (chestnut?)	0.885	American Elm	0.580
American Ash	0.772	Virginian Cedar	0.565
Beech	0.724	Yellow Pine	0.551
Hornbeam	0.720	Birch (poplar-leaved)	0.530
Wild Apple	0.697	American Horse-chestnut	0.522
Sassafras	0.618	Italian Poplar	0.397

The European woods, as shown in the first table above, are therefore rather less than one-half lighter than water, and a cubic foot weighs from 26 to 42 lbs. Wood dried in the air decreases in bulk, often as much as 0.1 of the whole.

* The Hanoverian pound is equal to 1.031114 lb. English.

A numerous series of experiments by Marcus Bull have proved that in an ordinary stack or pile of American wood, there is contained, for every 56 parts of actual wood, 44 parts of unoccupied space. This fact, in conjunction with the experiments on the specific gravity of different woods given in the table at page 7, led to the following actual quantity of wood in either given compass :—

	Pounds avoirdupois in a cubic meter. (35.3 cubic feet English.)	Pounds avoirdupois in a cubic foot.
Walnut (with scaly bark)	1227.6	34.7
White Oak (chestnut?)	1075.8	30.5
American Ash	919.4	26.0
Beech	880.0	24.9
Hornbeam	875.6	24.8
American Elm	704.0	19.9
Yellow Pine	668.0	18.9
Birch (poplar-leaved)	647.6	18.3
American Horse-chestnut	633.6	17.9
Italian Poplar	481.8	13.6

As wood that has been 12 months felled still contains about 25 per cent. of water, the foregoing numbers must be multiplied by $\frac{4}{3}$ in order to yield the actual amount of dry wood.

In mountainous districts, where the wooded parts are steep and intersected with rapid streams, the latter are frequently made subservient in transporting wood for fuel. In the Black Forest, in the neighbourhood of Salzburg, and in other places, large quantities of wood are floated down the rivers in this manner; but when this practice is more carefully looked into, it appears that the advantage of cheap transport is partly counterbalanced by the inferior quality of the wood so transported. Long immersion in water necessarily dissolves out all the soluble matters, and thus diminishes the volume of the wood, as well as its power of producing heat. Wernek asserts that 1 cubic foot of wood may lose 1 lb. of its weight by being floated.

When wood is burnt, it always leaves an incombustible residue, or ash; this residue consists of earthy and alkaline salts, which the living plant takes up from the soil, and which are essential to its healthy development. This ash consists of lime, potash, soda, oxide of iron, oxide of manganese, and silica, in combination with carbonic acid, chlorine, sulphur, sulphuric acid, and phosphoric acid. Many of the bases in the sap are in combination with organic acids, and these salts become carbonates on incineration. The greater part of the ash, indeed, is composed of the carbonates of lime and of the alkalies. The silica appears to exist in an uncombined state in the juices of the plant and the sulphur and phosphorus must be traced to the albuminous constituents of the latter.

The amount of ash varies with the kind of wood, and is likewise different in the several parts of the same tree and in trees of different age. The soil upon which the trees are grown has also some influence on the quantity and nature of the ash.

In some varieties of wood, the ash does not exceed $\frac{1}{2}$ per cent., whilst others contain from 2 to 5 per cent.

The following results were obtained by Berthier and Karsten from the incineration of several varieties of wood :—

Amount of Ash in 100 parts :—

Varieties of Wood.	I. BERTHIER.	II. KARSTEN.	
		In young wood.	In old wood.
Silver Fir (*Pinus picea*)	0.83	0.15	0.15
Birch	1.00	0.25	0.30
Scotch Fir (*Pinus sylvestris*)	1.24	0.12	0.15
Oak	2.50	0.15	0.11
Lime	5.00	0.40	—
Fir (*Pinus abies*)	—	0.23	0.25
White Beech	—	0.32	0.35
Alder	—	0.35	0.40
Red Beech	—	0.38	0.40

Berthier's results were obtained with air-dried wood.

More recent researches on this subject are those of Chevandier, and the following are the mean quantities of 524 determinations of ash which he has made :—

Wood.	No. of Determinations.	Mean Percentage of Ash.
Willow	17	2.00
Aspen	59	1.73
Oak	93	1.65
Hornbeam	73	1.62
Alder	26	1.38
Beech	93	1.06
Scotch Fir	28	1.04
Silver Fir	46	1.02
Birch	89	0.85

Portion of the Tree.	Percentage of Ash.
Young shoots, entire	1.23
Wood split into billets	1.34
Branches, entire wood	1.54
Faggots of twigs	2.27

COMPOSITION OF CERTAIN WOOD ASHES.

Constituents per cent.	Fagus Sylvatica.	Pinus Sylvestris.	Larix Europæa.
Potash	15.80	2.79	15.24
Soda	2.76	15.99	7.27
Lime	60.35	30.36	25.85
Magnesia	11.28	19.76	24.50
Manganic Oxide (Mn_3O_4)	—	18.17	13.51
Ferric Phosphate ($2Fe_2O_3,3P_2O_5$)	1.84	5.10	6.18
Tricalcic Phosphate	3.99		
Calcic Sulphate	2.30	3.31	2.91
Sodic Chloride	0.21	1.48	0.92
Silica	1.46	3.04	3.60
Total	99.99	100.00	99.98
Percentage of Ash in the Wood at 100° C. (212° F.)	—	0.143	0.322

These analyses are due to Böttinger.

Further particulars as to the composition of wood-ash will be found in the *Annalen der Chemie und Pharmacie* for 1843, 1844, 1845.

It has already been stated that the constituents of wood, as regards the relative proportions of their elements, do not differ much from pure woody fibre (wood purified from extractive matter and water). The knowledge of these proportions not only serves to explain the peculiar properties of the several woods, but is essential in estimating their relative values. Schödler and Petersen have furnished us with the following results derived from the elementary analysis of woods dried at 100° C. (212° F.) and previously pulverized:

In 100 parts they found the following relations:—

Species of Wood.	Carbon.	Hydrogen.	Oxygen.	Species of Wood.	Carbon.	Hydrogen.	Oxygen.
Pure woody fibre .	52.65	5.25	42.10	Populus nigra .	49.70	6.31	43.99
Quercus robur .	49.43	6.07	44.50	Tilia europæa .	49.41	6.86	43.73
Fraxinus excelsior	49.36	6.075	44.57	Salix fragilis .	48.44	6.36	44.80
Acer campestris .	49.80	6.31	43.89	Pinus abies .	49.95	6.41	43.65
Fagus sylvatica .	48.53	6.30	45.17	Pinus picea .	49.59	6.38	44.02
Betula alba .	48.60	6.375	45.02	Pinus sylvestris .	49.94	6.25	43.81
Ulmus campestris	50.19	6.425	43.39	Pinus larix . .	50.11	6.31	43.58

The following determinations of the elementary composition of some European woods have been lately made with great care by Chevandier.*

The specimens were dried at 140° C. (284° F.).

ELEMENTARY COMPOSITION OF SOLID WOOD, AFTER DEDUCTING THE ASH.

	Carbon.	Hydrogen.	Oxygen.	Nitrogen.
Beech . . .	49.89	6.07	43.11	0.93 mean of 7 analyses
Oak	50.64	6.03	42.05	1.28 ,, 5 ,,
Birch . . .	50.61	6.23	42.04	1.12 ,, 4 ,,
Aspen . .	50.31	6.32	42.39	0.98 ,, 3 ,,
Willow . . .	51.75	6.19	41.08	0.98 ,, 2 ,,

ELEMENTARY COMPOSITION OF BRUSHWOOD AND BRANCHES, AFTER DEDUCTING THE ASH.

	Carbon.	Hydrogen.	Oxygen.	Nitrogen.
Beech . . .	51.08	6.23	41.61	1.08 mean of 4 analyses
Oak	50.89	6.16	41.94	1.01 ,, 4 ,,
Birch . . .	51.93	6.31	40.69	1.07 ,, 3 ,,
Aspen . . .	51.02	6.28	41.65	1.05 ,, 2 ,,
Willow . . .	54.03	6.56	37.93	1.48 ,, 2 ,,

Although hydrogen and oxygen are contained in woody fibre in the same proportions as those in which they unite to form water (1 : 8), this relative proportion is not accurately observed in the different woods, the hydrogen being often contained in them in larger and in variable quantity. The composition of different woods does not vary, however, so much as might be anticipated.

* "Ann. Chim. Phys." [3], 10, 129.

As a general result, ordinary air-dried wood may be considered as being composed of:

20 per cent. hygroscopic water,
40 „ oxygen and hydrogen in the proportions in which they unite to form water,
40 „ charcoal, including 1 per cent. of ash.

Heated from 120° to 140° C. (248°—284° F.) the wood loses its hygroscopic water and becomes *kiln-dried*, and then contains:

50 per cent. of oxygen and hydrogen in the proportions in which they combine to form water,
50 „ charcoal, containing 1 per cent. of ash.

The wood is chemically changed when heated more strongly, as will be described under the head of charcoal.

TURF OR PEAT.

When a district is spread out in the form of a flat basin of greater or smaller dimensions, and the water which collects upon its surface or rises from springs, cannot freely escape, but stagnates for a length of time, a shallow lake is formed, as is not uncommon in the temperate zones, particularly where evaporation goes on slowly and the atmosphere is habitually moist, as, for instance, in Ireland. Under these conditions, water-plants of all kinds, sedges, rushes, reeds, algæ, mosses, more especially *Sphagnum*, even shrubby plants, as willows, &c., spread from the sides towards the centre of the pool, and quickly form a thick covering of vegetation. With the change of season, these plants die and fall to the ground, making room for a second crop in the following spring; this process goes on from year to year, until the shallow pool becomes a bog, and is at length completely filled up with a loose spongy vegetable mass. The remains of the plants immersed in water quickly decay; they lose their original solidity with the simultaneous evolution of gas (marsh gas and carbonic acid), and a disagreeable and noxious smell is produced; at the same time oxygen is absorbed from the atmosphere and from compounds, such as sulphates, contained in the soil and the water surrounding them, the sulphates being reduced to sulphides. The vegetable matters become brown and soft, and are eventually converted into a black-coloured, soap-like mass. The débris of plants reduced to this state by decay, or in which the process is still going on, is called *turf* or *peat*.

Such is now almost universally acknowledged to be the natural process by which peat has been produced, and the older hypotheses, that it is a formation as old as the hills and valleys where it occurs; a bituminous deposit from the sea; the wreck of once floating islands; or an actually growing vegetable substance, may be viewed as entirely exploded.

The plants from which turf seems to have been principally formed in the northern hemisphere are the mosses, amongst which *Sphagnum palustre* predominates. Besides these, heath and fern, rushes and reeds are frequent, and one or more species of cotton-grass (*Eriophorum*) are also common. Whole trees, oaks, firs, ash, birch, yew, and willow, have been frequently found at the bottom of peat-bogs, sometimes erect, as if they had been gradually buried by the encroaching growths of moss, in which they have ultimately perished, at others lying prostrate, in which position they may have aided in impeding the flow of water and in accelerating the growth of the bog. Human remains have been dug up in turf-bogs, sometimes in a state of high preservation, although the hair clothes and antique sandals afford evidence of a very long submersion; thus testifying to the powerful preservative or antiseptic qualities of the turf. Remains of animals now extinct, and fatty substances known as bog-butter, and

consisting principally, according to Brazier, of an acid which he calls *butyro-limnodic acid* ($C_{16}H_{32}O_2$),* support the foregoing statements.

In the southern hemisphere, according to Darwin, peat does not occur nearer the equator than the 45th degree of latitude, and the peat there formed is composed of the remains of almost all the plants growing in the vicinity, including the grasses; it is remarkable, however, that no mosses appear to have taken part in the formation of South American peat, which is chiefly composed of the remains of a plant called by Brown *Astelia pumila*.

Small deposits of turf are found in almost every country, but districts of immense extent occur upon the low shores of the North Sea and German Ocean (Holland and North Germany), in the formation of some of which the waters of the sea appear to have borne a part.

In mountainous districts, the hollows are frequently filled with peat-bogs, the constant assemblage of clouds upon the mountains favouring their growth by a gradual but incessant supply of moisture. These bogs, however, are seldom very extensive, nor does the deposit generally exceed 6 feet in thickness. In Holland entire districts are covered by this formation; in Britain the area of peat has been estimated by Hans Danchell at 6,000,000 acres, each acre being, in his opinion, capable of yielding 1000 tons of peat charcoal; whilst in Ireland one-seventh of the whole island, or an area of 2,830,000 acres, consists of peat-moor. In France, the great marsh of Montoire, near the mouth of the Loire, is said by Blavier to be more than 50 leagues in circumference. These vast growths of peat are deep in proportion to their extent, the moors of Holland averaging 2 fathoms, while those of Ireland are often 30 feet in depth.

Sometimes the peat formation appears to have taken place at successive periods; the layers are then generally separated by deposits of sand. Although peat sometimes comes quite to the surface, it is frequently covered with sand or mould, but is always found in horizontal layers of moderate thickness. Peat belongs to the more extensively diffused kinds of fossil fuel, and two kinds may be distinguished, differing in geological age, and in the amount of decomposition to which they have been subject. They are:

1. **Recent peat,** in which the structure of the roots and stems of the plants is still perfect; it is soft and exceedingly fragile, and of a very porous, specifically light texture. Passing from a light to a blackish-brown colour, and containing the roots and fibres which are really foreign to it disseminated through an earthy matrix, it gradually verges, without any marked distinction, into the

2. **Older peat,** in which all organic structure has disappeared, and the fibrous has given place to an earthy texture. Those kinds of peat are considered the oldest in which the structure has become so fine in the grain, so free from fibre, and so dense as to appear, when freshly cut, as smooth and shining as wax or pitch. All varieties of peat belonging to this class are distinctly heavier than those belonging to the former; whilst a cubic foot of the more porous kind only weighs about 4 lbs., the weight of a cubic foot of the old peat amounts to from 12 to 20 times as much (Karmarsh).†

* "Chem. Gaz." Oct. 1, 1852. Macadam has shown quite recently, however, that this fatty substance really has the composition of butter, and appears to be identical with it: "Journ. Chem. Soc. Abstr." 1887, p. 17, and "Min. Mag." 6, 175.

† The grand-duchy of Hesse comprises extensive peat-moors. The Rhine, formerly obstructed in its course at Bingen, was forced to spend its waters over the low-lands opposite Mayence, and the stagnating water which remained after the Rhine had forced its passage through the rocks at Bingen gave rise, in the still swampy district called Ried, to the formation of peat, which is now cut at Pfüngstadt and Griesheim. The peat of the latter locality is dense, heavy, and black, and closely related to the older peat; that of the former is light, without earthy constituents, rich in the roots of plants, of a light colour, and evidently belongs to the more recent species. The quality of the Griesheim peat is very superior to that from the other locality.

The humic acid contained in peat, and observed by Sprengel, as also the various other products of the decomposition of woody fibre, which constitute its chief mass, are of little interest as regards its application. The same may be said of the resins discovered in it by Mulder, and described by him.

Peat is cut and prepared for use in a very simple manner. In Ireland, Germany, and most other parts, the surface of the deposit is laid bare by removing the sod or earth above it, and the peat is cut into the shape of thick bricks with common spades, or with the slade, an instrument resembling a long spade with a portion of the blade turned up at right angles on the one side; the peats are then placed to dry, piled up loosely one against the other, or upon some kind of support. Care is taken to separate the peat of the upper part of the layer, which is young and fibrous, from the heavy and more plentiful lower peat.

The process adopted in Holland is somewhat more circuitous, but certainly more appropriate, exactly resembling the preparation of bricks by moulding. The peat is scooped with spades as long as practicable, and when the peaty mass, which is more spongy than solid, becomes too thin to be thus advantageously collected, a particular kind of instrument is substituted for the scoop commonly used upon such occasions. This consists of a kind of sharpened iron cylinder fixed to a handle forming, as it were, the side of the scoop; the cylinder is perforated with small holes on every side, and serves as a support for the bottom, which is formed of a net or piece of cloth. This instrument prevents any quantity of water being scooped up with the peat, the holes allowing the water to run off immediately. The peat-mud collected in this manner is converted into a homogeneous mass by treading with the feet and stirring about with rakes like mortar; the stones are picked out, and it is then spread out evenly in layers of one foot in thickness in large wooden boxes, such as are used for slaking lime, in order that the water may run off and the mass become dry. To facilitate this, and prevent the adhesion of earthy matter, the bottom of the box is previously covered with hay. After some days, when the mass exhibits a certain consistence, it is subjected to another operation, in which women and children are employed, who, instead of beating it, strap flat boards, like snow-shoes, to their feet, and stamp upon it in all directions. The treading is continued until no impression is produced by a common footstep: and the peat is lastly struck with beaters until the surface is uniform. The whole cake, eight or nine inches in thickness, is divided by means of long laths into squares of about four inches across. The thickness of the cake corresponds with the length of the bricks. To effect the complete desiccation, the first brick taken out is laid transversely upon the second, the third is laid upon the fourth, and so on; this order is afterwards reversed when the pieces are piled.

In some places, the peat-mud is scooped out with buckets on to a dry place, and the water being allowed to drain away, it is made into bricks with moulds. Too much water in the peat may completely destroy its value and render it incapable of being piled.

The value of peat is in proportion to its dryness, density, and firmness. If it possesses these qualities in a slight degree only, it suffers by carriage and by keeping, the upper layers of the heap compressing and breaking the lower layers, which are thus rendered valueless. The porosity and brittleness of peat prevent its application in all cases where the fuel and other matters to be heated are piled up to any considerable height one upon the other.

Dense peat comprises, in *an equal bulk*, much more combustible matter than porous peat. This fact has led, in recent times, particularly in Ireland, to the construction of presses for the purpose of improving the quality of the lighter kinds of peat, but the difficulty of introducing a machine which is at once rapid in its action, cheap, and effective, has not yet been entirely over-

come, the elasticity of the fibre offering great obstacles to the action of the press. It is evident that the use of a press, in addition to the advantages named, would also very much aid the drying process. In one experiment, a brick weighing 8 lbs. lost 2.5 lbs. of water under the press.

Where a large demand admits of peat being prepared on a manufacturing scale for consumption, the process introduced by Mr. C. M. Williams at Cappoge, in Ireland, has been employed, but we fear without much profit. It consists in breaking up the fibre of freshly-cut turf, placing it thus broken between cloths, and submitting it to the action of a powerful hydraulic press. The peat on leaving the press occupies only $\frac{1}{3}$ of its previous volume, and has lost about $\frac{2}{3}$ of its weight from the water which has been expelled. It is then denser than wood, although prepared from the lightest varieties of peat, and is said to have no tendency to re-absorb water. The cost of the process is not considerable, as the prepared peat can be delivered at 5*s.* per ton; the price of the unprepared material in the neighbourhood of the moors being 3*s.* 6*d.* per ton.

Water in Peat.—The longer peat is kept and allowed to dry in suitable sheds, the more it will improve as a heating agent. The spongy character of peat enables it to retain a large but very variable quantity of hygroscopic water. Karsten observed a loss of as much as 45 per cent. by simply drying freshly-cut peat in the air, but even when thus dried the quantity of moisture retained varied between 25 and 50 per cent., which could be driven off at a higher temperature. In the latter case, the specimens were probably not fully dried, and in this state the peat is principally consumed in this country and in Ireland, giving rise as it must do to a loss of heat equivalent to 30 per cent. Under any circumstances, peat dried in the air retains, in virtue of its porous structure, a larger proportion of water than wood under the same conditions. Thoroughly dried under cover, it is said to contain 10 per cent. of its weight of water. Ronalds found from 86 to 90 per cent. of water in freshly-cut peat, and from 53 to 56 in that dried in a room for several months, whilst peat dried in the open air only contained 30 per cent. of moisture. Messrs. Kane and Sullivan found from 10 to 24 per cent. of moisture in air-dried turf.* C. E. Bainbridge ("Proc. Cleveland Inst. of Eng.") found that a sample kept for some days under cover contained 16.4 per cent. of moisture, and that samples artificially dried regained nearly that quantity on exposure to the air.

Ash of Peat.—Another constituent, which is of little consequence in wood, is sometimes so abundant in peat as to render it quite useless; this is the ash, which is derived from two sources: first, the quantity of ash peculiar to the plants from which it has been produced, inasmuch as this has not been dissolved out by the bog-water; and second, the earthy matter which has been collected during the deposition of the peat. Peat-ash is essentially different in quality from the ash of wood, and varies in quantity to a much greater extent. Thus, in 100 parts of dried peat, the following quantities of ash have been observed:—

Variety of Peat.	Ash.	Observer.
Grass Peat, brownish-yellow	1—1.5	Karmarsh
Pitch Peat	1.2—8	
Young, dark-brown	5 to 7	
Old earthy Peat	10.	
Black, firm, from Neumünster	2.2	Suersen
" " Sindelfingen	7.2	Schübler
Brown, loose, " from Scheveningen	2.3	

* "Report on the Nature and Products of the Process of the Destructive Distillation of Peat," made to the Chief Commissioner of Woods, by Messrs. Kane and Sullivan, 1851.

Quantities of Ash in 100 parts of Dried Peat—(*continued*).

Variety of Peat.	Ash.	Observer.
Very old Peat, from Vulcaire, near Abbeville	5.58	Regnault
" " Lang "	4.61	
Not so old, from Champ de feu "	5.35	
Near Berlin, 1. Stage	9.3	Achard
" 2. "	10.2	
" 3. "	11.2	
Black, old, from Möglin	14.4	Einhof
Brown, young	14.3	
Moor, in Eichsfeld, 1. sort	21.5	Buchholz
" " 2. "	23.0	
" " 3. "	30.5	
" " 4. "	33.0	
In 41 sorts, from the Erzgebirge	1—24	Winkler
In 3 varieties from Holland and Friesland	4.61—5.58	Mulder
In 27 varieties from the central bog of Allen, in Ireland	1.120—7.898 mean 2.62	Kane and Sullivan
In 3 varieties from the neighbourhood of Tuam, in the west of Ireland	3.695—4.819 mean 4.545	Ronalds
In 9 varieties from Schnaditzer bog, near Schwemsal, in Saxony	5.30—37.10 mean 18.47	Wellner
Dumfries, Scotland	8.463	Heddle

Peat, therefore, may contain from 1 to 33 per cent. of its weight of ash. It is said that carbonates of the alkalies are never found in this ash; phosphates and especially sulphates are abundant, the former being in the form of phosphate of lime. Einhof found 15.25 lime, 20.5 alumina, 5.5 oxide of iron, 41 silica, 15 phosphate of lime, 1.55 common salt and gypsum, in 100 parts of ash; Schübler even found 34 per cent. of phosphates in the ash of peat from Scheveningen, to the presence of which its chief value as a manure is ascribed.

The ash of the three specimens analysed by Ronalds and noticed in the above table had the following composition :—

	I.	II.	III.
Potash	0.813	3.558	5.189
Soda	3.666	0.370	0.758
Lime	35.854	34.790	36.599
Magnesia	3.170	3.601	7.727
Alumina	4.423	2.801	3.440
Peroxide of Iron	2.565	6.345	6.499
Chlorine	4.327	0.432	0.596
Sulphuric Acid	12.860	19.703	16.463
Phosphoric Acid	2.194	3.567	2.816
Carbonic Acid	3.254	6.764	7.169
Silica soluble in Acid	4.744	3.337	4.898
Insoluble Matter	22.920	12.919	6.811
	100.790	98.187	98.965

I. Light peat from Ballinderry bog, taken at 4½ feet from surface. Bog 15 feet deep.

II. Somewhat older peat from Claretuam bog, taken 3½ feet from surface. Bog 16 feet deep.

III. Light peat from Wood Quay or Weirs' bog, taken 4½ feet from surface. Bog 22 feet deep.

The composition of the ashes of peat from the central bogs of Ireland has

COMPOSITION OF THE ASHES OF DIFFERENT PEATS.

	I.	II.	III.	IV.	V.	VI.	VII.	VIII.	IX.	X.	XI.	XII.	XIII.	XIV.
Specific Gravity	0.297	0.405	0.669	0.450	0.351	0.661	0.335	0.476	0.655	0 434	0.984	0.681	0.523	0.247
Potash	0.362	1.323	0.461	0.401	0.221	0 198	0 491	0.211	0.247	0.641	0.347	0.181	0.291	0.966
Soda	1.427	1.902	1.399	1.330	0.712	0.590	1.670	0.651	0.496	1.875	0.679	0.550	0 586	1.038
Lime	26.113	36.496	40.920	37.873	33.240	25.860	33.037	29.716	24.944	22.702	45.581	29 323	38.692	35.113
Magnesia	3.392	7.034	1.011	5.127	1.904	1.207	7.523	1.204	1.285	6.809	1.256	3.425	2 372	4.687
Alumina	4.180	5.411	3.793	0.271	0.240	0.371	1.686	0.298	0.360	1.109	0.129	0.672	0.408	1.627
Peroxide of Iron	11.591	15.608	15.969	14.802	12.760	13.746	13.281	20 372	19 405	29.854	15 974	19 095	15.537	14.322
Phosphoric Acid	1.401	2.571	1 406	1.257	1.222	0.874	1.438	1.066	0.242	2.019	0.188	0.975	0.878	0.828
Sulphuric Acid	12.403	14.092	14.507	11 814	21.470	23.630	20.076	22.664	10.742	16.381	44.371	16.238	14.822	25.409
Hydrochloric Acid	1.568	1.482	0.983	1.367	0.840	0.622	1.747	0.439	0.335	1.591	0.337	0.636	0.657	1.090
Silica in Compounds decomposable by Acids	0 980	3.595	1.111	1.002	1.672	0.896	2.148	0.645	1.082	0.737	1.043	3 255	5.808	5.607
Sand and Silicates undecomposable by Acids	22.519	2.168	2.107	4.722	13 147	14.430	7.683	11.180	26.789	14.505	2.653	8.884	14.181	4.340
Carbonic Acid	13.095	7.761	15.040	19.722*	12.060	12.240	8.340	10 782	13.890	1.470	16.120	15.984	5.842	5.003
Total	99.091	100.043	99 307	99.688	99.488	99.654	99.120	99.228	98.812	99.693	99.678	99.218	100.074	100.030

	XV.	XVI.	XVII.	XVIII.	XIX.	XX.	XXI.	XXII.	XXIII.	XXIV.	XXV.	XXVI.	XXVII.
Specific Gravity	0.394	0.437	0.323	0.924	1.058	0.481	0.629	0.280	0.546	0.855	0.402	0.441	0 858
Potash	0.407	0.665	0.668	0.280	0.744	1.667	0.271	0.146	0.247	0.219	0 370	0.028	0.158
Soda	2 074	2.605	1.709	2.180	0 704	2.823	1.491	0.466	1.150	0.855	2.628	2.832	0.527
Lime	33.397	33 554	31.553	30.744	40 623	20.907	13.667	8.492	22.332	40.079	27.732	26.551	12.432
Magnesia	11.293	9.229	9.439	9.237	4.352	15.252	16.994	4 702	5.608	4.035	6.875	12.580	3.095
Alumina	1 627	0.677	1.707	2.027	1.671	2.034	0.359	10.705	0.932	0.895	1.521	3.298	5.991
Peroxide of Iron	18.500	18.366	6 012	19.797	10.368	17.040	26.644	15.052	29 970	14.160	7.451	12.116	30 725
Phosphoric Acid	0.744	1.300	1.286	1.290	1.114	1.447	1.339	1.557	0.699	0.632	1 670	2.022	0.526
Sulphuric Acid	13 550	23.505	25.602	20.857	24 208	23.375	22.691	13.974	31.612	22.295	20.389	22.401	14.518
Hydrochloric Acid	2.804	3.263	0.698	3.128	1.052	1.424	1 180	0.196	0.993	0.781	2.932	2.581	0.151
Silica in Compounds decomposable by Acids	5.998	4 449	5.159	3.096	6.317	6.634	2.719	12.476	2.751	1.295	7.709	5.474	9 101
Sand and Silicates undecomposable by Acids	6.593	3.040	6.282	3.163	3.710	10.682	11.673	31.198	3.775	5.496	10.088	17.711	22 721
Carbonic Acid	3 006	—	9.864	3.570	4.981	6.721	—	—	—	9.101	10.460	1 220	—
Total	99.993	99.653	99 979	99.369	99.844	100.006	98.964	98.928	100.069	99.843	99.825	98.751	99.945

* The quantity of carbonic acid found by experiment is in nearly every case much less than that required to saturate the lime, supposing the whole of the sulphuric acid to exist as sulphate of lime; this is accounted for by the greater part of the carbonic acid having been driven off by the high temperature necessary to incinerate the peat.

been examined in 27 specimens by Kane and Sullivan, the details of which may be found in their report before alluded to. We subjoin their results.

I.—Light spongy surface peat, reddish-brown colour, composed almost entirely of *Sphagnum*, species still distinguishable; from near Monastrevin.

II.—Light surface-peat, reddish-brown colour, containing small roots of *Erica*, and leaves of grasses and *Carex;* from Mount Lucus bog, near Phillipstown, King's County.

III.—Rather dense peat, dark reddish-brown colour, structure of moss still distinguishable; from the same locality as II.

IV.—Light reddish-brown fibrous moss-peat. *Sphagnum* almost unaltered, as well as leaves of *Carex* and other plants, and the roots of species of *Erica;* from Tichnevin, Kildare.

V.—Upper layer of fibrous red bog, composed entirely of *Sphagnum*, *Hypnum*, and other mosses; from Derrymullen station of the Irish Amelioration Society.

VI.—Dense peat of blackish-brown colour. Vegetable structure nearly obliterated, leaves of grasses and *Carex*, and twigs of hazel and apparently of birch sometimes found. Wood of Allen, Great Timahoe bog.

VII.—Light surface-peat, pale yellowish-brown. Mass very open, grained, and fibrous. *Sphagnum* and *Hypnum* readily distinguished; from Wood of Allen.

VIII.—Middle layer of same bog, deep reddish-brown colour. Mass tolerably compact, but still fibrous. Structure of the moss very indistinct. A very few roots of *Erica* and small twigs of birch and alder, and scales of fir; from Wood of Allen.

IX.—Lower layer of same bog. Compact and dense, deep blackish-brown, fracture earthy, appearing almost conchoidal, and exhibiting a resinous lustre when rubbed. The appearance of vegetable structure almost entirely obliterated. Wood of Allen.

X.—Good compact peat, blackish-brown colour, principally consisting of moss, with a good many roots of *Erica* and grasses, *Carex*. Used as fuel in Dublin; from Riversdale bog, near Kinnegad.

XI.—Excessively hard compact peat. Vegetable structure completely obliterated; some pieces exhibiting a perfectly resinous conchoidal fracture. Scales of fir-trees and twigs of birch, alder, &c., sometimes occur. A valuable fuel. Baltinoran and Rawson bogs, near Kinnegad.

XII.—Very dense dark reddish-brown peat. Vegetable structure only occasionally perceptible; from Anadruce and Cloncreim, on the Royal Canal.

XIII.—Rather dense peat, of a dark reddish-brown colour. Structure of *Sphagnum* very indistinct, but leaves of the flag, and stems and roots of *Erica* occur in a perfect state. Structure compact; from bogs of Rathconnel, Wood Down and Great Down, near Mullingar.

XIV.—Upper layer of fibrous bog. Mass spongy and of a yellowish-red colour. Composed of almost unaltered *Sphagnum*, with occasional roots of *Carex*, *Erica*, &c., from the neighbourhood of Banagher.

XV.—Rather compact peat, of reddish-brown colour. Vegetable structure very perceptible, but impossible to distinguish species; roots of *Erica* abundant, but the greater part evidently derived from moss. Same locality as XIV.

XVI.—Still more compact peat than XV., consisting of fibrous or red bog, colour light reddish-brown. Structure of mosses still visible, but species cannot be discriminated, roots and leaves of *Carex* exceedingly abundant. Same locality as the two preceding.

XVII.—Light surface-peat, of a pale reddish-brown. Mass spongy and composed of almost unaltered *Sphagnum*, with a few stems and roots of

Erica; from the bogs of Clonfert and Kilmore, at the mouth of the river Suck, near Banagher.

XVIII.—Rather compact peat, of a light reddish-brown colour, fibrous, but passing into black peat. Structure of mosses still perceptible. Abundant remains of *Carex* and grasses; from the same locality as XVII.

XIX.—Exceedingly dense dark blackish-brown peat, fracture earthy, sometimes conchoidal. Vegetable structure almost completely destroyed; but when apparent, remains of *Carex*, grasses and *Erica* abundant; from Athlone bog.

XX.—A rather dense peat, of a blackish-brown colour, in which the structure of moss is no longer visible, but abounding in remains of *Carex*, grasses and roots and stems of *Erica;* from Curragh or Clonbourne bogs, near Shannon Bridge.

XXI.—A dense peat, of a dark reddish-brown colour. Remains of *Carex* and grasses very abundant, but *Sphagnum* much compressed and structure very indistinct; from bogs along the Shannon. Used in steamers plying on the river.

XXII.—Light fibrous peat, of reddish-brown colour, evidently formed of a great number of plants. Structure of moss very distinct. Species of *Sphagnum* and *Hypnum* distinguishable. Remains of *Carex* and grasses, with roots of *Erica*, and bark of birch, and probably alder-twigs abundant. Same locality as XXII.

XXIII.—Very dense peat, of a blackish-brown colour. Mass compact. Vegetable structure very indistinct. Remains of *Carex* abundant, and roots of *Erica* frequent. An excellent fuel. Same locality as XXII.

XXIV.—A very dense blackish-brown compact peat. Vegetable structure almost obliterated. Fracture earthy. Full of tubes of the bark of hazel, birch, and alder, and occasionally scales of pine-bark, and leaves of *Carex* and grass. Same locality as XXII.

XXV.—A rather dense reddish-brown peat. Structure very indistinct. *Carex* leaves altered, and occasionally a few fragments of twigs and roots. Same locality as XXII.

XXVI.—Rather compact and moderately dense peat, of a dark reddish-brown colour. Structure of moss almost obliterated. Abundance of leaves, stalks and roots of grasses, *Carex*, &c. Same locality as XXII.

XXVII.—Dense jet-black peat. Structure of moss completely destroyed. Fracture earthy, tending to conchoidal, assuming resinous lustre when rubbed. Abundance of remains of *Carex* leaves, and a very few fragments of bark, apparently of hazel. Same locality as XXII.

Density of Peat.—The weight of peat depends on its state of dryness, and its age. Karmarsh gives the following relative weights for different kinds of Hanoverian peat:—1. Light-coloured, young grass peat, nearly unchanged moss, 0.113 to 0.263. 2. Young brown and black peat, an earthy matrix intersected with roots, 0.240 to 0.600. 3. Old earthy peat without any fibrous texture, 0.564 to 0.902. 4. Old peat, pitch peat, 0.639 to 1.039. Moulded peat from Griesheim (near Darmstadt), of good quality, has been found to weigh 0.706, so that 1 cubic foot would weigh on an average 22 lbs. and 100 bricks (at 56 cubic inches), 123.5 lbs.* After incineration, these leave a mass of ash, which, although less in bulk, retains the form of the brick, and is very considerable in quantity.

Sir R. Kane estimates the specific gravity of light surface-peat at about 0.400, and from this it increases, with the compactness of the substance, to nearly the density of coal. A cubic yard weighs, packed closely in sods,

* 1000 pieces of Griesheim peat are calculated at 74,300 c. f. and weigh 1170 lbs.
" " Pfungstädt " " 75,600 " " 820 "
" " " best and driest " 49,000 " " 660 "

about 900 lbs. The densest turf will weigh as much as 1,100 lbs. per cubic yard, whilst the lightest may not weigh more than 500 lbs. Compared with coal in fragments as employed in the furnace, peat is about ½ as dense. A cubic yard of coal averages about 13 cwt.

The maximum specific gravity of peat from the series of 27 specimens of all kinds and characters from the great bogs in the centre of Ireland, as given, pp. 17, 18, by Sir R. Kane and Dr. Sullivan,* is 1.058, and the minimum 0.235; the greater number of specimens being, however, below 0.6.† The quantity of water contained in these specimens, after being dried in the air, ranged between 10.446 per cent. in a specimen taken from the middle layer of a bog, and 33.270 per cent. in a very dense compact specimen, in which vegetable structure was very indistinct. The mean quantity in the 27 specimens was 21.6.

A cubic foot of the earthy peat examined by Karmarsh gave nearly 3 lbs. of ash; a quantity which must be very prejudicial in many of its applications; partly from the dust which it makes and the space it occupies;‡ and partly by its chemical action in smelting processes, destroying the bars of grates, besides decreasing, of course, the quantity of combustible matter.

The conditions under which peat is produced would have a tendency to increase the amount of carbon above that contained in woody fibre. Regnault and Mulder have both examined the elementary composition of different varieties of peat; and the following are their results, after deducting the amount of ash stated in the previous table:—

Localities.	Carbon.	Hydrogen.	Oxygen.	Analyst.
Vulcaire	59.57	5.96	34.47	Regnault.
	60.40	5.86	33.64	Mulder.
Long	60.06	6.21	33.73	Regnault.
	60.89	6.21	32.90	Mulder.
Champ de Feu	60.21	6.45	33.34	Regnault.
	61.05	6.45	32.50	Mulder.
Friesland	59.42	5.87	34.71	,,
,,	60.41	5.87	34.02	,,
Holland	59.27	5.41	35.32	,,

There is a very small quantity of nitrogen in peat which is recognized by the ammoniacal vapours it produces when heated.

It would thus appear that peat differs essentially from wood in elementary composition. The former may be viewed as consisting of carbon and water in equal proportions by weight, whilst in the latter, the entire amount of oxygen being supposed in combination with hydrogen to form water, we have the following relative proportions in 100 parts:—

Carbon	60
Hydrogen	2
Water	38
	100

or an excess of 10 per cent. carbon and 2 per cent. hydrogen over that contained in dried wood, whilst the amount of water is reduced 12 per cent.

The following analyses of specimens of Irish peat show also the amount of

* "Report on the Nature and Products of the Process of the Destructive Distillation of Peat, considered especially with reference to its Employment as a Branch of Manufacturing Industry." London, 1851.

† For details of these, see Table, p. 17.

‡ In a fire, which converted 320 lbs. of water into steam in 9 hours, 240 lbs. of peat were consumed. The ash of this, calculated at 20 per cent., would leave 48 lbs. daily on the hearth, and amount in the year to 175 cwt., the removal of which would be attended with much expense and trouble.

nitrogen which they contain. The ash was deducted in calculating these results so as to exhibit the actual composition of the organic matter :—

	Carbon.	Hydrogen.	Oxygen.	Nitrogen.	Ash.	
				mean.		
Surface Peat, Phillipstown (Sp. II. p. 17)	58.694	6.971	32.883	1.4514	1.992	Kane and Sullivan
Dense Peat, Phillipstown (Sp. III. p. 17)	60.476	6.097	32.546	0.8806	3.305	
Light Surface Peat, Wood of Allen (Sp. VII. p. 17)	59.920	6.614	32.207	1.2588	2.745	
Dense Peat, Wood of Allen (Sp. XX. p. 18)	61.022	5.771	32.400	0.8070	7.898	
Tichnevin Peat (Sp. IV. p. 17)	60.102	6.723	31.288	1.8866	2.629	
Upper Shannon (Sp. XVII. p. 17)	60 018	5.875	33.152	0.9545	2.474	
Upper Shannon (Sp. XXIV. p. 18)	61.247	5.616	31.446	1.6904	2.976	
Kilbeggan, Westmeath	61.04	6.67	30.46		1.83	Kane
Kilbaha, Clare	56.63	6.33	34.48		8.06	
Cappoge, Kildare	51.05	6.85	39.55		2.25	

The following may also be added to the list; in these the ash is not deducted :—

Ochta, in Eastern Russia	39.084	3.788	51.088		6.04	Woskresensky
Peat, 4½ ft. from surface, Tuam, Ireland	57.207	5.655	28.949	3.067	5.122	Ronalds
,, 3½ ft. ,, ,, ,,	58.306	5.821	29.669	2.509	3.695	
,, 4½ ft. ,, ,, ,,	59.550	5.502	28.414	1.715	4.819	

These results confirm generally the above remarks. It appears from the table of ash analyses, that the amount of sulphate of lime and phosphoric acid does not depend on the position occupied by the peat in the bog, but rather on local circumstances; that during the formation of peat the greater part of the alkali and phosphoric acid originally contained in the plants has been removed; and that the amount of silica is very small, especially in the fibrous varieties.

The proportion of carbon and hydrogen contained in different specimens of peat does not vary much, although the lower layers generally contain a little more carbon than those near the surface.

Use of Peat.—Heating Effect.*—The practical application of peat for heating operations depends greatly on the amount of moisture it contains, and the degree of condensation to which the peat has been reduced has also an important bearing on its economic value, affecting as it does the bulk which has to be transported and its power to resist handling and transport.

Karsten states that for evaporative and boiling operations

2½ parts by weight of peat are equal to 1 part by weight of coal

4 ,, volume ,, ,, 1 ,, volume ,,

This is borne out by some experiments quoted by D. K. Clarke ("Fuel and its Combustion," &c.) from a paper by Mr. W. Anderson, of Erith. Mr. Anderson reports some comparative experiments carried out at St. Petersburg on the evaporative effect of coal, wood, and peat in double-flued multitubular cylindrical boilers. The fire-grate area was 30 square feet and the heating surface 696 square feet. The peat was of compact quality, and had been moulded by hand into 4-inch balls and air-dried until the moisture did not exceed 14 per cent.

* Refer to "Proc. Inst. C.E.," vol. xxxviii.: "Peat Fuel Machinery," by J. McCarthy Meadows. Also to "Proc. Inst. C.E.," vol. xli. (1874-75), p. 202.

Locality and Description of Fuel.	Fuel consumed per hour.	Water evaporated per hour at 100.4° F.	Water evaporated at 212° F. per lb. of Fuel.
Abouchoff Steel Works, 1870–74.			
Superior Coal	450	49.5	7.57
Inferior „	515	51.0	6.76
Wood cut 1 year, still damp . . .	796	38.6	3.25
Wood dried artificially	538	40.4	5.00
Peat	—	—	4.26

The *average* of the results obtained at Erith and St. Petersburg with coal was 8.55 lbs. water evaporated per lb. coal, which shows the relative value of peat to be one-half that of coal.

C. E. Bainbridge quotes some tests with Thompson's calorimeter, which give a better result than the above—viz.:

Peat in its usual state showed a calorific power = 4.675
„ dried „ „ = 5.94

But the following remarks from Crookes and Röhrig's Metallurgy are strictly to the point:—

"1 lb. of dry turf will evaporate 6 lbs. of water; now, in 1 lb. of turf as usually found there are $\frac{3}{4}$ lb. of dry turf and $\frac{1}{4}$ lb. water. The $\frac{3}{4}$ lb. can only evaporate $4\frac{1}{2}$ lbs. of water; but out of this it must first evaporate the $\frac{1}{4}$ lb. contained in its mass, and hence the water boiled away by such turf is reduced to $4\frac{1}{4}$ lbs. The loss is here 30 per cent., a proportion which makes all the difference between a good fuel and one almost unfit for use. When turf is dried in the air under cover, it still retains one-tenth of its weight of water, which reduces its calorific power 12 per cent.; 1 lb. of such turf evaporates $5\frac{1}{3}$ lbs. water. This effect is sufficient, however, for most of the purposes for which it is used; the further desiccation is too expensive and too troublesome to be used except in special cases."

FOSSIL FUEL, OR COAL.

The steady and gradual operations of nature, at the present day, supply certain districts with a stock of fuel of no mean quality, by the constant interment of the lower kinds of vegetation in the manner already described; but in the earlier periods of the earth's history far more extensive stores of invaluable combustibles were laid up for the future use of mankind.

The most valuable of all the species of fuel is coal, and its discovery and application have been attended with increased prosperity in all those countries which are so fortunate as to possess it.

Coal is a dark-brown or black mineral, of no great degree of hardness, varying from 1.2 to 1.8 in specific gravity, burning with a more or less brilliant flame and much smoke when ignited. It occurs in horizontal or more or less inclined layers, alternating with clay, and frequently with ironstone, chiefly in the geological formation which, from this circumstance, has been named the Carboniferous, and which takes position in the series of sedimentary deposits between the lower Silurian or primary fossiliferous formations on the one hand, and the New red sandstone on the other. Anthracite, the oldest species of coal, is also found in the most recent members of the transition formations; whilst brown coal, the youngest variety, occurs in the chalk.

There appears no reason to doubt the vegetable origin of coal. The gradual metamorphosis of woody fibre into coal can be traced chemically,

step by step, through the various stages; upright fossil trees, with their roots resting in seams of coal, testify to their growth upon the site in which they remain carbonized, whilst modern transformations of forests into peat-bogs, in which the trees remain erect, afford the strongest analogical evidence of the manner in which many of the ancient coal-fields may have been produced. Botanists who have paid particular attention to the fossil flora of these deposits are generally agreed in ascribing them to the accumulation and gradual decomposition of ferns, some of which were arborescent, and to vegetable forms belonging to *Calamites*, *Lepidodendra*, *Sigillariæ*, and *Stigmariæ;* palms, though rare, are sometimes found. Altogether not less than from 200 to 300 species of plants have been found in the coal measures.

The character and habits of these plants would indicate that a very different temperature and climate, and indeed an altogether different distribution of land and water, must have existed at the time of their growth and subsequent interment. They belong to a class of vegetation which flourishes in an extremely moist, warm, and equable climate, with the absence of any severe cold; the circumstances and meteorological conditions under which they grew, therefore, must have been very different from those which characterize the coal districts of the present day. A tropical climate was at one time considered essential to the growth of these vegetable forms, and a very large excess of carbonic acid in the atmosphere above that contained at the present time has been assumed in explanation of their gigantic development. Although closely allied to tropical plants, those of the coal formation are still so distinct, that the former assumption does not appear necessary; indeed the flora of the southern coasts of New Zealand, situated in the 46th degree of latitude, is stated to bear the strongest resemblance to that of the coal formations.

From considerations of this kind, it has been reasonably inferred that, at the time of the carbonaceous deposits, the northern hemisphere was pervaded by a great ocean interspersed with numerous islands of small dimensions, bearing insular or submarine volcanoes, a combination of geographical circumstances not unfavourable to the growth of a flora like that from which these deposits have been formed. Alternate elevations of sea and land, islands springing up by volcanic agency from the bottom of the ocean, might cause the waters to overflow and submerge the less elevated lands, and bury with them the forests and vegetation under layers of mud and sand. A series of alternate changes of this character might possibly account for the various coal deposits.

By some it has been supposed that the coal-fields resulted from collections of drifted timber deposited in the deltas of rivers at the time of their overflow. This supposition is supported by the fact, that many of the large rivers of North America, particularly those which flow from south to north, are known to tear up and carry away, on the breaking up of the ice, numbers of large trees. which, having been completely soaked by long immersion in water, become heavy and sink, and are gradually buried in the deltas under mud, sand, and the débris of rocks, or are drifted by the currents of the ocean to more remote and quiet localities, there to undergo the process of carbonization. Heat and moisture, with the partial access of atmospheric air, appear to have been the active agents in carbonizing the buried vegetation, assisted at a later period by immense superincumbent pressure in consolidating it.

Coal is met with in more recent geological formations than the one to which it has given its name. The deposits therefore differ considerably in age, and two distinct species of coal may easily be distinguished, as well by their physical as chemical peculiarities. All coal that occurs above the chalk

is of comparatively recent origin; the process of decay is less advanced, and it is evidently much more allied to wood, than that which lies below the chalk. The former is called *brown coal*, or *lignite*, whilst many varieties of the latter are classed together under the common name of *bituminous* or *pit-coal;* that variety in which the carbonization is most complete being called *anthracite*. Whilst the entire structure of the wood is retained almost unchanged in the first, it has disappeared completely in the last two, with the exception of a few rare impressions of plants. All the varieties may be viewed as derived from woody fibre, the carbon of which for the greater part has remained, while the other elements have gradually diminished and disappeared in proportion to the age of the formation, until in the last product, *anthracite*, hardly anything but carbon is left. This is the result of a process which may be distinctly traced by comparing the elementary composition of the different members of the series.

The composition of woody fibre in 100 parts, as given at page 10, corresponds closely with the formula $nC_6H_{10}O_5$.

An important feature in the progressive decomposition of buried wood, is the production of carbonic acid from the elements of the wood. In the case of the formation of brown coal, where atmospheric oxygen is not so completely excluded, this element combines also with a portion of the hydrogen; this does not occur in the formation of coal. In the latter case, the elements of woody fibre are simply resolved into the four products: carbonic acid, water, light carburetted hydrogen, and coal. In the former, the mouldering process is predominant, but decay (eremacausis) also performs its part; the formation of coal, on the contrary, is exclusively a mouldering process. It is more than probable that the carbonic acid accompanying the mineral waters of the carboniferous deposits, is produced at the same time as the light carburetted hydrogen, which has been observed to constitute the chief mass of the fire-damp of coal-mines.

Cumulative Resolution.—Supposing, for the sake of simplicity, that $n = 1$ in the formula of woody fibre, the primary or fundamental change which woody fibre undergoes is one of successive dehydration. Thus

$$nC_6H_{10}O_5 - (n-1)H_2O = nC_6H_{5n+2}O_{4n+1}$$

represents the formation of every possible stage in the removal of the first H_2O; and, when n becomes infinite, the removal will be complete, and we shall have the body whose formula is $C_6H_8O_4$. Proceeding as before,

$$nC_6H_8O_4 - (n-1)H_2O = nC_6H_{6n+2}O_{3n+1},$$

which becomes $C_6H_6O_3$ when n is made infinite. In this manner, the additional hydrates $C_6H_4O_2$ and C_6H_2O will be obtained, and then intermediate stages may be similarly represented. The limit of the entire series is of course nC_6, a pure carbon in one of its polymeric forms; but it is unlikely that this point is ever really attained in any process of natural decay, or natural or artificial destructive distillation. The whole process, which is very common in every department of chemistry, is called by Mills "Cumulative Resolution."

The actual work of dehydrating cellulose and its congeners leads eventually to carbon and water as the principal products. It is, however, well known that, with increasing complexity or numerical value of formula, proneness to variation in chemical change increases. Accordingly we find that, in the destruction of cellulose by heat and decay—or, in the language of symbols, as n is made infinite over and over again—the number of bye-products increases, and the main or stem-substance eventually ceases to be exactly constituted in the ratio $C_6 : mH_2O$ Coal, for example, always contains H in excess of this ratio, known under the name of "disposable hydrogen;" and, in the formation of coal and peat, hydrogen, carbonic acid, and marsh gas are all given off. According to Mills, the formation of bye-products is mainly

observable at or after the period when the stem-substance has the composition $C_6H_6O_3$.

Coal is met with in three distinct geological formations. Commencing with the lowest, we find it:

1. In the *coal measures*, which may be subdivided into the older *transition series* (anthracite), and the younger *coal*.

2. In *secondary formations*, both in the older members of the new red sandstone (*Keuper* of the Germans), in the limestones of the oolite group which constitute the Jura, and in the more recent *chalk*.

3. In *tertiary deposits*, as fresh-water limestone, shell limestone, &c., with *brown coal*.

Brown Coal, or Lignite.—The coal of the tertiary formations is not always uniform in appearance. In some kinds, the vegetable remains are so well preserved, their structure so distinctly retained, even the more tender parts, as leaves and fruit, so little altered, that a botanical diagnosis of the antediluvian plants has been undertaken with success. They consist of flattened stems, crossing each other in all directions, of a more or less dark colour, soft and mellow in consistence when freshly quarried, but becoming brittle by exposure, the fracture following the direction of the fibre of the wood. This variety is known by the name of *lignite, fossil* and improperly bituminous *wood*. Bovey coal (from Devonshire), and the coal of the Wetterau (Salzhausen, Laubach) in Germany belong to this class (it is also called, from its texture, *fibrous brown coal*). In other kinds, there are only occasionally distinct indications of vegetable structure, and they appear throughout as a stratified mass, of a dark colour, nearly black. They have an earthy fracture and are called *earthy brown coal;* to this class the coal of Meissner, near Cassel, belongs. Those varieties in which the fracture is conchoidal and the structure more dense have been distinguished as *conchoidal brown coal* or *pitch coal*. Lignite is frequently mixed with these, and both kinds are often present in the same specimen. Although sometimes occurring at the surface, these fuels are usually obtained from a considerable depth.

Water in Brown Coal.—Fresh from the pit, the lignites are impregnated with water, which evaporates on exposure to the air, the amount of evaporation depending on their degree of porosity and the temperature. Reinsch found lignite, from the Bavarian Upper Pfalz, to contain 43, and earthy brown coal, from the same locality, to contain 30 per cent. of water. The amount of moisture in brown coal is, however, generally greater; at least Varrentrapp found that fresh coal, from Helmstedt and Schöningen, contained 48 per cent. of water. After being completely dried (when a great reduction of volume occurred), these coals re-absorbed 8 per cent. of moisture. Coal of this kind, kept for some time piled up, contained 29 per cent. of water; after exposure to the air in summer, 20; and in a warm room after four weeks, 8 per cent.

Ash.—The amount of ash in brown coal itself is not very large; it is, however, frequently increased to an injurious extent by the infiltration of water containing salts, and by an admixture of earthy matter, as will be seen from the following table:—

Variety of Brown Coal, or Lignite.		Ash.	Observer.
		Per cent.	
Bohemian	Lignite from Aussig	5.35	Balling
	,, ,,	5.51	
	,, Hegendorf	6.93	
	,, Neuendorf	5.13	
	,, Coulang	1.50	
	Earthy from Grünlas	6.66	
Bavarian Ob.-Pfalz	,, ,, Verau	10.00	Reinsch
	Lignite ,, ,,	3.40	
	,, ,, Greece	9.02	Regnault
	,, ,, Usnach	2.19	
	,, ,, Cologne	5.49	
	Earthy brown coal from Dax	4.99	
	,, ,, ,, Bouches du Rhône	13.43	
	,, ,, ,, Nieder-Alpen	3.01	
Cassell	,, (*Stangen*) coal, ,, (*Pitch*) coal — Meissner	15.47	Kühnert
	,, (*Pitch*) coal — Meissner	2.43	
	,, ,, from Hirschberg — Ringkuhl	0.81	
	Pitch coal ,, ,, — Ringkuhl	2.76	
	Middle sort ,, ,, — Ringkuhl	3.20	
	Lowest sort ,, ,, — Ringkuhl	4.92	
	Pitch coal from Habichtswald	1.33	
	,, ,, ,,	3.33	
	Stillberger coal (Söhrwald)	6.95	
	Lignite from Hirschberg	1.29	
	,, Iceland	8.8	
	,, ,, (another specimen)	27.5	Karsten
From Duren, on the left bank of the Rhine	,, Utweiler	0.9	
	,, Grube Urwelt	4.6	
	,, ,, ,,	27.05	
	,, Friesdorf	1.69	
	,, ,,	14.9	
Near Bonn, on the right bank of the Rhine	,, Putzchen	4 4	
	,, ,,	17.4	
	,, Stösschen	14 4	
	,, ,,	28.2	
	,, Orsberg	43 2	
	,, ,,	58 0	
	Coal from Schöningen — Brunswick	7.8	Varrentrapp
	,, Helmstädt — Brunswick	8.4	
	Slate coal from Azberg	4.5	Reinsch
	,, ,, Aga Reuss	6 0	
	Earthy lignite from Wigan	4.95	J. A. Phillips
	,, ,, Conception Bay	7.49	Admiralty Coal Investigation
	Lignite from Sandy Bay, Patagonia	13.29	
	,, Talcahuano Bay	6.92	
	,, Artern, Germany	1.16	Kremers

The amount of ash, even in the same deposit and in different parts of the same piece, varies more than is the case with peat; as may be seen from Karsten's experiments. The general conclusion to be drawn from these results is, therefore, that the amount of ash in brown coal varies from 1 to 50 per cent. In most cases, however, it is not less than 5, and seldom above 10 per cent. Reinsch found in the ash of lignite, from Verau:

Sulphate of Lime	3.6
Hyposulphite of Potash	1.9
Hyposulphite of Lime	25.4
Protosulphate of Iron	50.
Sand	20.
	100.9

The ash of earthy brown coal yielded

Sulphate of Lime	3.
Hyposulphite of Lime	7.
Protosulphate of Iron	57.
Sand	33.
	100.

Varrentrapp found in the ash of brown coal from Brunswick:

Sulphate of Lime	57·5
Magnesia	2.58
Alumina	11.57
Oxide of Iron	5.78
Carbonate of Potash	2.64
Silica and Clay	19.27
	99·34

Brown coal, such as that of Orsberg, consisting of one half mineral matter, cannot be considered fuel, but can be made use of for other purposes (see ALUM).

Nitrogen in Brown Coal.—In addition to the ash and the elements of wood, brown coal contains from 0.5 to 1.5 per cent. of nitrogen, which has not been separately estimated in the following analyses:—

Brown Coal contains (in addition to the Ash, * see page 25)	Carbon.	Hydrogen.	Oxygen & Nitrogen.	Observer.
Earthy, from Dax	69.52	5.59	19.90	Regnault
,, Bouches du Rhône	63.01	4.58	18.98	
,, Nieder-Alpen	69.05	5.20	22.74	
Earthy, consisting of stems, from Meissner	70.12	3.19	7.59	Kühnert
,, pitch coal from Meissner	56.60	4.75	27.15	
,, ,, ,, Ringkuhl, Hirschberg	60.83	4.36	24.64	
,, ,, ,, Habichtswald	57.26	4.52	26.10	
,, lustrous coal, Ringkuhl	66.11	4.82	18.51	
,, allied to pitch coal, Habichtswald	54.18	4.20	26.98	
,, lowest vein, at Ringkuhl	52.98	4.09	21.91	
,, middle ,, ,,	54.96	4.01	22.31	
,, Stillberger	50.78	4.62	21.38	
,, Helmstädt, Prince William mine	68.57	4.84	19.87	Varrentrapp
,, ,, another mine	67.88	6.85	17.46	
,, Schöningen, Treue mine	63.71	5.07	22.79	
,, ,, another pit	64.80	4.54	23.12	
Lignite, from Ringkuhl	51.70	5.25	30.37	Kühnert
,, Greece	60.36	5.00	25.62	Regnault
,, Cologne	63.42	4.98	27.11	
,, Usnach	55.27	5.70	36.84	
,, Laubach	57.28	6 03	36.10	Liebig
Earthy brown coal, from Wigan	80.21	6.30	8.54	J. A. Phillips
,, ,, ,, Conception Bay	70 33	5.84	16.34	Admiralty Coal Investigation
Lignite from Sandy Bay, Patagonia	62 19	5.08	19.44	
,, Talcahuano Bay	70.71	6.44	16.93	

The actual organic portion of brown coal in its different modifications according to the analyses of Regnault is therefore as follows:—

	Locality.	Character.	Carbon.	Hydrogen.	Oxygen & Nitrogen.
Lignite, fossil wood, or fibrous brown coal	Greece	Laminated, black, with indications of organic structure	66.36	5.49	28.15
	Cologne	Ligneous texture, friable, brownish-red in powder	66.04	5.27	28.69
	Usnach	Fossil wood, woody texture, very hard	56.50	5.83	37.67

Analyses of Regnault—*continued.*

	Locality.	Character.	Carbon.	Hydrogen.	Oxygen & Nitrogen.
Earthy brown coal, or perfect lignite	Dax . . .	Fine black, irregular fracture, no ligneous texture . .	73.18	5.88	21.14
	Bouches du Rhône	Slaty, black and brilliant, no ligneous texture . .	72.78	5.29	21.93
	Mont Meissner .	Brilliant, conchoidal fracture	72.00	4.93	23.07
	Basses-Alpes .	Black, fatty lustre . .	71.20	5.36	23.44
Pitch coal, conchoidal brown coal or lignite passing into bitumen	Ellnbogen . .	Compact, homogeneous, fracture conchoidal . . .	76.58	7.85	15.57
	Cuba. . . .	Black, like velvet, fatty lustre	77.88	7.55	14.57

The mean of these experiments, after deducting the ash, would lead to the following general composition for the organic portion of the varieties of brown coal :—

	Carbon.	Hydrogen.	Oxygen and Nitrogen.
Fibrous brown coal . .	63	5	32
Earthy ,, . .	72	5	23
Pitch ,, . .	77	7·5	15·5

The whole of the oxygen being supposed combined with hydrogen to form water, the composition would then be nearly as follows :—

	Carbon.	Hydrogen.	Water.
Fibrous brown coal . .	63	1	36
Earthy ,, . .	72	2	26
Pitch ,, . .	77	5·5	17·5

The weight of air-dried brown coal varies within narrow limits; the specific gravity of the specimens of lignite examined by Regnault varied from 1.100 to 1.85; that of the earthy coal, from 1.254 to 1.276. Kühnert found the latter to vary from 1.310 to 1.436, whilst lignite had a specific gravity of 1.279, and the lignites examined by the officers of the Admiralty Coal Investigation varied from 1.291 to 1.321. A cubic foot of brown coal will therefore weigh on an average 80 lbs., but the absence of uniformity in the nature of the substance hardly admits of applying to a larger quantity the weights obtained from experiments on a small scale. The numbers found clearly show that the variations are independent of the amount of ash.*

Use of Lignite.—From a paper by M. Sylvain Périssé, in the *Mémoires et Compte-rendus des travaux de la Société des Ingénieurs Civils* of Paris (No. 28, 1874, p. 768), it appears that at the date of his communication the use of lignite in metallurgical operations connected with iron manufacture was carried out on an extensive scale in Tuscany. The lignites used contained from 40 to 50 per cent. of moisture and 15 per cent. of ash. They were air-dried, and used in the gas-producers connected with Ponsard furnaces for reheating and puddling iron and for firing boilers. With a turnout of 6,800 to 7,000 kilos. per furnace per twenty-four hours, the consump-

* In the grand-duchy of Hesse brown coal has been found at the following places:—1. In Upper Hesse, near Lauterbach or Zell, at Laubach (Hessenbrücken), Salzhausen, Friedberg (Dorheim, Bauernheim), Eberstadt, Obererlenbach, Grünberg (Zeche Buderus). 2. In the province Starkenburg, near Seligenstadt.

tion of lignite was 585 kilos. per ton of iron charged or 638 kilos. per ton of finished iron.

On railways in Italy, it was ascertained that when the lignite did not contain more than 15 per cent. of moisture, two tons of it were equivalent to one ton of coal briquettes.

Prof. Tunner, of Leoben, Austria, discussed the use of lignite in the blast-furnace before the Iron and Steel Institute in 1882 ("Jour." vol. i. 1882, p. 96), but from the experience gained in Austria in that application of this fuel he recommended the use of a mixture of brown coal and ordinary coke or coke made from the small of brown coal mixed with some good coking-coal.*

At the steel works at Teplitz, in Bohemia, it appears, from a paper by K. Wittgenstein and A. Kurzwernhart (in "Jour. Iron and Steel Inst.," No. ii. 1882, p. 451), that for the daily manufacture of twenty charges of six to six and a-half tons each of steel, by the Bessemer process, about 1,320 cubic metres of brown coal were used and 1.6 cubic metres of coke. The brown coal was used for melting the charges of iron in Siemens' regenerative furnaces, for heating the converters, and for raising steam; grates of the shelf and step-grate form being successfully used.

When wood is not available, lignite is often used in Austria in the salt-works for evaporating the brine. The heat required for this purpose is not intense, so that the ash is not apt to form clinkers in the furnaces.

The plan of compressing lignite into blocks, with subsequent drying of the blocks, is recommended for Prussian lignites by R. A. Schultz (see *Zeit. für Berg- Hütten- und Salinenwesen*, vol. xxiv. p. 234; also "Proc. Inst. C. E.," vol. xlviii. p. 349). Several plans are proposed, and the author gives statistics of cost of the process and plant and of the value of the products. The following table sums up the general properties of the different classes of this fuel:—

	Wet Coal as raised.	Hand-moulded Blocks.	Wet-pressed Blocks.	Dry-pressed Blocks.
Specific gravity	1.22—1.29	1.24—1.31	1.26—1.32	1.20—1.22
Proportion of water per cent.	42.30—47.00	32.10—35.40	26.60—30.00	17.20—21.50
Proportion of ash per cent.	6.00—9.30	7.70—13.80	8.60—10.50	10.00—14.20
Heating power	183—209	179—223	231—287	254—315
Cohesive power	—	0.17—0.22	0.38—0.45	0.68—0.74
Condensation in volume per cent.	—	36 4	50.1	56.6
Value per 1 hectolitre of coal in pence	1½—2½	3—3¼	4½—6¼	6¾—7¼

MINERAL OR PIT COAL.

Coal in a Geological point of view.—Geologically speaking, coal is a stratified rock, always found in beds interstratified with other stratified rocks, clays, sandstones, and limestones. The only difference between coal and clays, sandstones and limestones, is, that whilst they are formed principally of mineral matter merely enclosing organic remains, coal is formed principally or entirely of organic remains.

In some few instances, the organic remains may have formed parts of animals, but in the greater number of cases (so great as to be nearly

* An important paper on this subject by F. Frederici in *Oest. Zeitschr. f. Berg. u. Hutt.*, 1882, Nos. 1 to 5, is noticed in "Jour. Iron and Steel Inst." No. i 1882, p. 286.

universal) the remains are those of plants. These vegetable remains, having been deposited in thick beds or layers, each layer extending over an area sometimes of many square miles, were covered up by other beds of sand or mud, and subsequently converted into coal. How this conversion took place is a question for the chemist to decide. Pressure no doubt aided it, and some degree of heat, but perhaps not a greater degree than would arise from the decomposition of the plants themselves. The thickness of the beds varies from a mere film or layer of a ¼ inch in thickness up to 3 or 4 feet. No single bed of coal, probably, is ever thicker than 3 or 4 feet, and rarely exceeds half that. Where a seam of coal reaches 8 or 10 feet, and *à fortiori* where it reaches 30 or 40, it is composed of two or three or more beds resting directly one on the other, or separated by thin layers of clay or earthy matter, which are commonly called "partings."

These thin layers of earthy matter—fine mud originally—are so frequent as to be almost universal in all beds of coal whenever they are traced over any distance—and they sometimes, even when not more than an inch or two in thickness, extend over areas of many square miles. They are the result of tranquil deposition of sediment in water, and prove the coal to have been under water at the time of the formation of the "parting." Beds of coal, which in one locality come together, resting one on another directly or with only the intervention of a "parting," are in other places separated by many feet, or sometimes even many yards (30 or 40, for instance), of interposed beds of sandstone and clay. The same would be found to occur in all sedimentary stratified rocks, if any one or two beds of them were traced accurately over wide areas in the same way as beds of coal are by mining operations. There is, in short, no peculiarity or mode of occurrence in beds of coal which is not common to other beds of regularly stratified sedimentary rock.

We should, therefore, be at once inclined to decide that the materials of coal had been deposited under water, having been drifted into their present position, become water-logged and sunk, just as the materials forming sandstones and clays have been drifted and sunk to the bottom, were it not for some other circumstances which make it probable that coal was often the result of the deposition of the remains of plants on the spot where they grew, and that that spot was dry land. Every bed of coal, for instance, has under it a bed of clay—usually fire-clay, but sometimes arenaceous, or even sandstone itself—crowded with the remains of plants that are now known to be roots, and the roots of stems that are so frequently found associated with coal that they evidently contributed largely to its formation. Botanists tell us that these stems were not those of aquatic, but of land plants. Upright stems, moreover, of trees have been found under such circumstances as almost to prove them to be in the position of growth, and in some beds of coal that have been worked by "open work" (quarrying, that is to say), stools of trees have been found in abundance close together in the substance of the coal, and in ranks one above another in its different layers.

It is supposed, therefore, that many beds of coal were formed, not by drifted plants, but by plants that fell and died on the spot where they grew, that spot being afterwards depressed beneath the level of water from which the sedimentary masses of sandstone and clay were deposited upon them. It is probable that coal was the result sometimes of one, sometimes of the other method of accumulation.

The varieties of coal may depend on the varied nature of the plants that composed it, the various circumstances attending their deposition, or the varied conditions under which the beds have subsequently been placed. If coal were formed under water, mud or earth may have been deposited along with it; if it grew above the level of the water, occasional floods may have brought in earthy matter over and among it. This we see in our peat-bogs

at the present day. Many of the clays or shales in the "coal measures" contain a greater or lesser amount of carbonaceous matter intimately mixed up with them, and this occasionally to such an amount that they will for a time support combustion and give off gas. This may be observed often in our parlour fires, in what are called "slates," but which ought to be called "shales," and which in Staffordshire and other coal fields are called "batts" or "basses." Some coals, moreover, have such an amount of earthy matter mingled with them that they support combustion but indifferently when compared with other coals. It hence arises that there is every possible gradation, arising from the mixture in various proportions of mineral and organic matter, from a mere clay up to the purest coal; and it would be quite impracticable to draw any line of distinction between a "carbonaceous (or bituminous) shale" and an "earthy coal." The same person would give the different names to the same substance according to the subject or object he had in view.

Moreover, the same bed of coal which is earthy, impure, or "batty" in one place, will in another be a pure and excellent bituminous coal. By bituminous we must in all cases understand, not containing bitumen, but containing little else but the constituents of bitumen—namely, carbon and hydrogen. All kinds and varieties of coal, therefore,—cannel, caking, stone, and anthracite,—graduate insensibly into each other, not only by different beds having different qualities, but sometimes by the same bed changing gradually in its different portions. Coal, therefore, although it may be said to be organic matter mineralized, cannot be called a "simple mineral," but is a "rock," or mechanical mixture of substances in various proportions and degrees, those substances having become indurated and compacted together,—partly by mere pressure, partly by the chemical action of the constituents,—just as many sedimentary rocks, containing a variety of substances—calcareous sandstones, magnesian limestones, and ferruginous shales—have become changed, or "mineralized," so to speak, not only by pressure, but by the chemical reaction on each other of their several constituents. Their origin having been mechanical aggregation, their subsequent consolidation has been the result of the mechanical and chemical conditions under which they have been placed.

Coal is in Britain principally confined to a certain set of rocks, called the carboniferous, occupying a posterior place in the series of stratified rocks. Wherever that set of rocks has been found in other parts of the world, it has been also found to have beds of coal. Coal, however, is by no means confined to that set of rocks, but is found in different parts of the globe in different parts of the series, from the Devonian down to the most recent tertiary rocks. In all periods of the earth's geological history, wherever an accumulation of plants took place, and that accumulation was subsequently buried under beds of sand and mud, coal was the natural and apparently the inevitable result.

Mineralogical characters of Coal.—The mineralogical characters of coal are very various. Anthracite appears to be almost amorphous and uncrystalline, whilst most other varieties break up into cubical or rhomboidal fragments. The fracture is either conchoidal, uneven, fibrous, or slaty; in some cases, as in Boghead, it is conchoidal perpendicular to the plane of stratification, but slaty when parallel.

The colour runs through all the shades, from light brown in the case of some of the Scotch cannels, to the velvet black of the caking coal of Newcastle, whilst the streak following the colour passes into a brownish yellow in some specimens.

Some varieties can scarcely be said to have any lustre,—as the Wemyss, Methil, and other cannels,—from which there is a gradual transition to the

shining resinous caking coals, terminating with the splendent semi-metallic and beautifully iridescent anthracites; and every possible variety between these extremes.

With reference to hardness, the anthracite variety, possessing a hardness of 2.0 to 2.5, perhaps stands at the head of the list, from which we descend through the difficultly-frangible splint of Glasgow, the sectile cannels and jet, down to the brittle, soft soiling coals of the north of England.

The following table gives the range of the specific gravities of the different varieties:—

America—Rhode Island anthracite	1.7500	America—Madison Town caking	1.5600
Ditto Pennsylvania „	1.5500	Scotland—Glasgow splint	1.2900
Ireland—Kilkenny „	1.4354	America—Johnson's Run ditto	1.4930
Wales „	1.3750	Turkey—Silivria 1.346 to Rodosto	1.5300
France—Canton of Lanton, near Prendle. anthracite	1.0720	Scotland—Wemyss cannel	1.1831
England—Hetton caking	1.2740	Ditto Boghead „	1.1990
Ditto Garesfield „	1.2800	England—Incehall „	1.2550
Nova Scotia—Picton „	1.3250	Scotland—Rocksoles „	1.4480
France—Megecoste „	1.4900	America—Blossburg „	1.7500

Coal in a Chemical point of view.—The chemical composition of coal varies even more than the mineralogical characters, but, in one respect, substances acknowledged by one party or another to be coal, differ in not yielding bitumen to any of the numerous reagents which have been employed for this purpose.

Dr. Fyfe obtained the following results by acting on different coals with naphtha:—

	Per Cent. of Matter soluble in Naphtha.
Newcastle caking	4.2 5.8 9.8
Cannel coal, No. 1	2.
Ditto No. 2	3.
Ditto No. 3	4.
Halbeith cannel coal	1.5
Capeldrae ditto	0.0
Torbane ditto (black)	1.2
Ditto ditto (brown)	1.4

The carbon varies—

From 70.12 per cent. in anthracite from Meissner to 94.10 per cent. in that from Pembrokeshire.

From 56.77 per cent. in cannel from Capeldrae to 83.75 per cent. in that from Incehall.

From 74.82 per cent. in splint from Wylam to 82.92 per cent. in that from Glasgow.

But the same extremes do not exist in all bituminous coals.

The hydrogen varies to a much greater extent among coals generally, but not so much in coals of the same description. Thus we have 1.49 per cent. in the anthracite of the Isère deposit, and 8.86 per cent. in the cannel of Boghead.

The same remarks apply to the oxygen, no oxygen being present in some of the French anthracites, and as much as 15.51 in coal from the Dalkeith jewel seam. The most striking relation of these two elements exists in the Boghead cannel, where, with 8.86 per cent. hydrogen, there is only 3.62 per cent. oxygen; to which circumstance Mr. Lewis Thompson very properly attributes much of the peculiar valuable properties of this coal.

There is nothing very noticeable in the proportions in which the sulphur,

nitrogen, &c., are present, especially as the former may exist either as sulphide of iron, sulphate of lime, or in combination with the organic elements.

The quantity of ash varies much more than any of the other ingredients, which is quite consistent with the origin of coal: thus in—

Semi-bituminous coals we have from	2.80	to	23.69	per cent. ashes
Bituminous do. do.	1.70	to	33.88	do.
Anthracites, American do.	1.28	to	68.00	do.
British coals do.	1.20	to	26.50	do.

which generally consist of the same ingredients, derived from the associated stratification, as the following analyses by Kremers and Tayler, and those previously quoted by Phillips, prove:—

Constituents.	1	2	3	4	5	6	7	8	9	10	11
Silica	15.48	45.13	60.23	31.30	1.70	3.12	62.44	59.56	64.21	56.51	58.90
Alumina	5.28	22.47	31.63	8 31	2.12	29.50	31.22	12.19	28.78	31.89	26.19
Ferric Oxide	74.02	25.83	6.36	54 47	60.79	32.78	2.26	15.96	2.27	—	5.14
Ferrous Oxide	—	—	—	—	—	—	—	—	—	7.04	5.11
Lime	2.26	2.80	1.08	3.44	19.22	20.56	0.75	9.99	1.34	1 69	0.67
Magnesia	0.26	0.52	0.35	1.60	5.03	2.16	0.85	1.13	1.12	0.85	1.54
Potash	0.53	0.60	0.11	0 07	0.35	0.99	2.48	1.17	2.28	1.38	2.34
Soda	—	0.28	—	0 29	0.08	1.72	—	—	—	0.61	—
Sulphate of Lime	2.17	2.37	0.24	0 52	10.71	9.17	—	—	—	—	—
	101.53	100.60	98.37	98 95	99.30	100.00	100.00	100.00	100.00	99.97	99.98

1. Glance coal from Oberndorf, near Zwickau.
2. Zwickau compact glance coal.
3. Zwickau light soft coal.
4. Waldenburg coal.
5. From the coal formation at the Inde.
6. Brown coal from Arlern.
7. Newcastle fire-clay from between the coal seams.
8. Newcastle coal, after deducting 8.2 per cent. sulphuric acid.
9. Inferior ditto, after deducting sulphuric acid.
10. Shale, after deducting 39.35 per cent. organic matter.
11. Shale, after deducting 11 per cent. clay.

The following is the relation of silica and alumina (including other substances in small quantity) in the Scotch cannel coals:—

	Boghead.	Lesmahago.	Capeldrae.
Silica	69	48	53
Alumina, &c.	31	52	47
	100	100	100

When submitted to distillation, all varieties of coal, with few exceptions, yield the same solid, liquid, and gaseous products, consisting of coke, tar, ammoniacal liquor, benzene, toluene, &c., naphthalene, paraffin, paraffin oil. and illuminating gas, the proportions among which vary with the quality of the coal and the temperature employed.

In the "Journal of the Society of Chemical Industry," 1885, p. 325, numerous data have been collected and discussed by Mills, as to the composition of the organic matter in coal and shale, and the results of its destructive distillation. As will be observed, he arrives at the conclusion that this destructive distillation proceeds preferentially in such a manner as to distribute C_3 groups in the distillates and residue.

"In constructing equations to represent the transformations of coal and other complex bodies, I shall, for the sake of convenience, frequently employ collocations of symbols to indicate mean composition; it will be understood

that these collocations are not intended to suggest separate chemical compounds.

"Prof. W. Foster ('Proc. Inst. C.E.,' April 1884) has completely analysed and distilled at a high temperature, two samples of Yorkshire and one of Durham coal. His mean results, apart from sulphur, nitrogen, pit-water and ash, correspond to the following relations:—

$$2C_{24}H_{18}O = 33C + C_{15}H_{34}O + H_2O.$$

Organic Matter in Coal.	Fixed Carbon.	Gas and Tar.	Organic Water.
(Calc.) 100	61.5	35.7	2.8
(Found) —	61.5	38.5	

"Foster has also similarly examined a Scotch cannel. His data may in like manner be reduced as follows:—

$$2C_{12}H_{12}O = 12C + C_{12}H_{22}O + H_2O.$$

(Calc.)	41.9	52.9	5.2
(Found)	41.3	58.7	

"In my work on 'Destructive Distillation' (2nd ed. p. 28) I have shown that the organic matter in a good average Scotch shale has almost exactly the composition $C_6H_{10}O$. According to additional data (*loc. cit.* p. 26), reduced as before, the changes which this undergoes at a low temperature may be represented by the equality.

$$7C_6H_{10}O = 18C + C_{24}H_{62}O_2 + 4H_2O.$$

		Fixed Carbon.	Gas and Oil.
(Calc.) 100	31.5	58.0	10.5
(Found)	31.2	58.3	10.5

"At a high temperature, we have the relation

$$7C_6H_{10}O = 6C + C_{36}H_{62}O_2 + 4H_2O.$$

		Fixed Carbon.	Gas and Tar.
(Calc.) 100	10.5	79.0	10.5
(Found)	12.8	76.0	11.2

"The Heywood cannel gas coal, which may be taken as representing an average Scotch cannel, has (*loc. cit.* and special communication to the author) been analysed and distilled. The reactions are—at a low temperature—

$$4C_9H_{12}O = 27C + C_9H_{46}O_3 + H_2O.$$

		Fixed Carbon.	Gas and Tar.
(Calc.) 100	59.6	37.1	3.3
(Found)	58.1	38.3	3.6

and at a high temperature—

$$4C_9H_{12}O = 24C + C_{12}H_{46}O_3 + H_2O.$$

		Fixed Carbon.	Gas and Tar.
(Calc.) 100	52.9	43.8	3.3
(Found)	52.5	43.9	3.6

"The results for Boghead coal are as follows:—At a low temperature—

$$3C_{12}H_{20}O = 15C + C_{21}H_{46}O_2 + H_2O.$$

		Fixed Carbon.	Gas and Oil.
(Calc.) 100	33.3	63.3	3.3
(Found)	33.3	64.1	2.6

At a high temperature—

$$3C_{12}H_{20}O = 6C + C_{30}H_{58}O_2 + H_2O.$$

		Fixed Carbon.	Gas and Tar.
(Calc.) 100	13.3	83.3	3.3
(Found)	12.8	84.6	2.6

"There is thus considerable evidence in favour of the definite character of the destructive distillation of coal and shale. It is probable that the organic matter in these minerals can be always represented with an nC_2 formula; and that a very simple relation exists between the C of the fixed carbon on the one hand, and the C of the [gas and tar (or oil)] on the other. It is clear also that C_2 is the fundamental unit, or stable condition, in these effects; and that not less than this unit must be removed from, or left in, the 'fixed carbon' during destructive distillation. Hence it is hopeless to expect that, for instance, more than fractional variations in the yield of oil from a shale can be effected by modifications in modern retorting."

Coal in a Technical point of view.—The great technical applications of coal are in the manufacture of coke, of illuminating and heating gas, the reduction of metalliferous ores, and in direct heating operations.

In respect to the first no coal yields a merchantable coke which does not cake, but all coals yield a residuum containing what is termed *fixed carbon*, more or less mixed with ash; in this respect they differ from most shales, which leave no fixed carbon, as is shown by the table below, and by others at the end of the volume.

	Shales, &c.		
	Stirlingshire Coal-field.	Pendleton, Lancashire.	Fife Rums.
Combustible matter . .	16.53 ...	22.53 ...	26.74
Fixed carbon . . .	— ...	— ...	20.51
Ash	83.47 ...	77.47 ...	52.75
	100.00 ...	100.00 ...	100.00

A shale seldom contains more than 20 per cent. of inflammable matter when the water it naturally contains is deducted, whilst the amount of ash averages from 82 to 83 per cent. Most shales yield little or no bitumen to naphtha, and in this respect they resemble coal; but there exist shales, properly called bituminous shales, that afford considerable quantities of bitumen.

Dr. Fyfe has shown,* by a numerous series of experiments, that the relation of volatile to non-volatile matter in coals of the most varied description, omitting the anthracites, is from 37 to nearly 67 per cent., and the amount of coke yielded consequently varies from 33 to 63. The proportion of fixed carbon and of ash also varies, the former from about 18 to 52, and the ash from 3.6 to 28.5 per cent. These characters at once distinguish coal from bituminous shales, of which he furnishes the following analyses and comparison with the Torbane Hill cannel coal:—

TABLE OF THE COMPOSITION OF SHALES.

Shales.	Volatile Matter.	Non-volatile Matter.	Non-volatile Matter.	
			Fixed Carbon.	Ash.
Above Dysart iron-stone . . .	19.	81.	7.	74.
Under Craig coal	7.8	91.2	6.	86.2
Roof of ditto	7.7	92.3	0.	92.3
Ditto of wood coal	7.	93.	8.	85.
West Wemyss	13.5	86.5	2.5	84.
Lancashire (1)	15.9	84 1	7.7	76.4
Ditto (2)	13.14	86.86	7.9	78.96
Ditto (3)	7.7	92.3	8.8	83.5
Average	11.46	88.53	5.98	82.54
Torbane mineral	69.	31.	12.	19.

* "Journal of Gas-lighting," vol. iii. p. 588.

As regards the manufacture of gas, the following table of results of the distillation of various coals on a small scale illustrates Dr. Fyfe's statement as to the relation of volatile to non-volatile matter in coals :—

Names.	Coke.	Tar.	Water.	Ammonia.	Carbonic Acid.	Sulphuretted Hydrogen.	Olefiant Gas, and other Hydro-Carbons.	Other Gases, inflammable.	Authority.
Welsh coals—									
Graigola . .	85.50	1.20	3.10	0.17	2.79	trace	0.23	7.01	Admiralty Report
Jones's anthracite .	92.90	trace	2.87	0.20	0.06	0.04	?	3.93	
Oldcastle fiery-vein .	79.80	5.86	3.39	0.35	0.44	0.12	0.27	9.77	
Ward's fiery-vein .	—	1.80	3.01	0.24	1.80	0.21	0.21	—	
Binea . . .	88.10	2.08	3.58	0.08	1.68	0.09	0.31	4.08	
Llangennech . .	83.69	1.22	4.07	0.08	3.21	0.02	0.43	7.28	
Newcastle coals—			Gas Water.				Total Gas.		
Ramsay's cannel .	68.79	9.02	0.73		1.33	0.52	19.61		Richardson
Cowen's ditto . .	70.37	8.33	0.97		1.18	trace	19.15		
Wallsend caking .	70.28	11.70	1.11		0.92	0.49	15.50		
Hutton seam ditto .	74.99	8.77	1.23		1.00	0.26	13.75		
Walker ditto . .	72.47	11.00	1.06		0.35	0.48	14.64		
Pelaw main ditto .	74.50	9.70	1.10		0.46	0.24	14.00		
Scotch coals—									
Edinburgh cannel .	60.35	16.10	0.80		3.02	0.34	19.39		Browell
Boghead ditto . .	46.75	24.00	0.55		0.20	trace	28.50		
Prussian Rhine . .	83.40	6.30	0.40		trace	0.08	9.82		

Microscopical Examination of Fuel.—For the substance of the following investigation of the microscopic structure of coal we are indebted to Aitken, of Glasgow :—

The external characters of fossil fuel, as seen by the naked eye, are not always a sufficient index of the qualities of the substances, for two bodies apparently similar may be microscopically different.

The following series of allied bodies have been examined for the purpose of this inquiry :—

1. *Peat* and *turf* from England, Scotland, Ireland, and Germany.
2. The German and English *lignites*.
3. The Scotch and English *cannel* coals.
4. The English and American *gas coal*, not of the cannel kind.
5. *Household* and *coking* coal.
6. Welsh and American *anthracites*.
7. Native *asphalt*, elastic *bitumen* and *shale*.
8. Simple *stratified mineral* bodies.
9. *Vegetable tissues* growing at the present day, and allied to the plants found in the carboniferous strata.

Before proceeding to the microscopic examination of fuel, it may perhaps assist our object to introduce here a few remarks on the scalariform tube or ladder-like tissue to which reference will often be made. In such tubes the deposit of cellulose seems to take place in such a way as to leave marks, bars, or fine lines running across the tube, so that the vessel appears as if broken up into spaces resembling the steps of a ladder. In ferns, this tissue assumes a prismatic columnar arrangement. Receptacles of secretion exist also in some parts of plants, and consist of special canals or cavities containing oily, fatty, or resinous matter. Hard substances, which have received the name of sclerogenous or gritty tissue, also frequently fill the interior of cells, as in the pulp of the pear and hard part of shells. In some instances the organic portion of the tissue may be removed by nitric acid, and siliceous matter is left in the form of the original structure.

How far these and other elementary structures are preserved or altered during the process of transformation into coal or allied fossil substances, has now to be examined.

I. *Peat.*—Theories of the most varied kind have been proposed to explain the nature and formation of peat; but the general conclusion is, that peat in its usual form consists of a matrix of vegetable matter, enclosing earthy material, and is for the most part made up of the fibres, roots, and leaves of many different species of plants.

Examined by the microscope, carefully selected portions from beds of peat show the process of transformation from the recently living vegetable fibre to the compact lignite, jet, or even coal itself. Distinct and characteristic microscopic appearances are associated with the carbonization of the varied materials and its farther transformations. The experiments of Lindley and Goepert show that the persistence of structure in plants immersed in water depends very much on the power which particular families of plants possess of resisting the decomposing action of water.

The process of transformation becomes more and more apparent by the deposit of a black amorphous matter in and upon the walls of the cells, which under the microscope appears to be nothing but carbon, and at first occurs in a very definite manner. The granular deposit is noticed first in the interior of the cells and upon the walls of the tubes which compose the vascular tissue of the plants, so that the process of transformation appears to begin with these. This metamorphosis continues until the original anatomical appearance of recent vegetable tissue is completely destroyed, becoming opaque, granular, and amorphous by the deposit of the black substance.

The evolution of gaseous products ruptures the cells, and the vascular tissue becomes separated, so that the cells and fibres gradually pass into an amorphous mass of a black colour, or into a homogeneous yellow resinous-like substance.

These are the changes which take place where the air is partially excluded, but, when it has access, the mass assumes a more earthy aspect, and the elements of the tissues moulder down into granular particles. The gaseous products, when they cannot bodily escape, tend to break up the tissues as they become confined within the cells or between the tubes. The burial of vegetable matter in the earth thus shuts out the action of the air, and exposes it to the action of mineral matter, either the result of its own decomposition or that of surrounding strata.

This process of change is very gradual, and is much influenced by local circumstances; some of the forests in our own country which have been submerged prior to all tradition, still retain all their ligneous characters. The timber of a forest exposed on the sea-coast near Whitburn, in the county of Durham, had not suffered any important change in its microscopic vegetable character, except where it had been exposed to the decaying action of the weather. When stems of wood exist in the lowest strata of peat, as in many samples of the Allenhead Moor peat, it is completely blackened in colour, and easily reduced to a soft clay-like paste. When examined microscopically, it presented an appearance characteristic of brown coal or lignite, retaining the granular or general form of woody tissue, as seen by the naked eye. The minute structure of the elementary vegetable tissue is completely obliterated and replaced in many parts by the black opaque matter already described. (Compare Plate A, Fig. 1.)

The process of histolysis, or retrograde decay, has been artificially imitated by Goepert, who found the product formed could in no respect be distinguished from brown coal. Some portions escape, as the bark and siliceous parts of the stem, as well as some kinds of plants, as the coniferæ and arducaria, or Norfolk Island pine, which perhaps owe their preserva-

Plate I. A

Vegetable tissue preserved or uncoalified in the substance of various Coaly Matter.

Fig. 1.

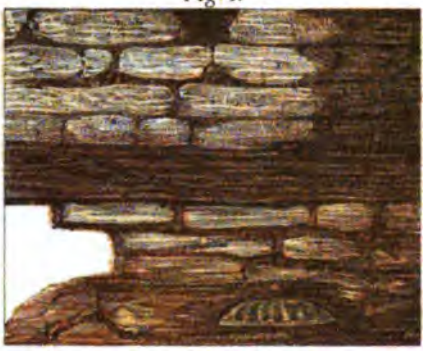

Fig. 2.

Fig. 3.

Fig. 4.

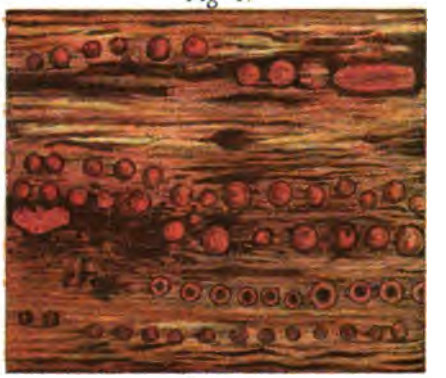

Fig. 5.

Fig. 6.

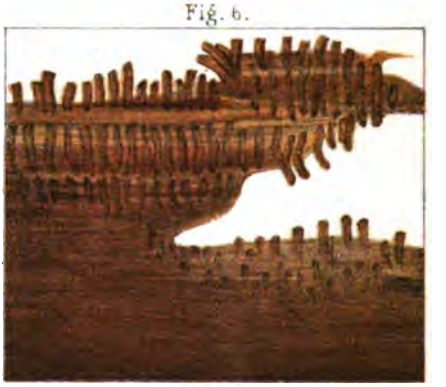

Fig. 7.

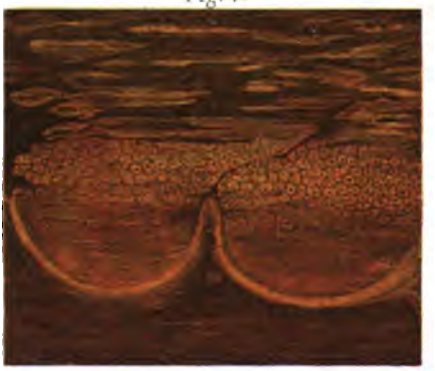

Fig. 8.

W. Huth Lith. Edin.

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PLATE A. (I.)

Fig. 1.—Structure of the more condensed portions of peat, from Allenhead's Moors, 10 feet below the surface. It shows the vegetable tissue undergoing the transforming process. Black matter is deposited in and round the boundaries of cell tissue, in some parts producing perfect opacity. In some places the elongated cells are perfectly distinct and well preserved. At the lower part of the figure a solution, or softened-down-like appearance, marks the nature of the change. A stratified and more condensed lamellar arrangement is seen in the centre of the figure.

Fig. 2.—Horizontal section of German brown coal, or lignite of the Rhine. The dotted tissue in some parts is distinct, and characteristic of the coniferous woods; in others the dots, glands, or cavities are distended, and are of very various sizes. They are filled with the yellow or brown substance so characteristic of the yellow volatile element in gas-coal. The tissue is altered in this way partly by the distension of these discs or cavities, and partly by the deposit of black matter.

Fig. 3.—Transverse section of German brown coal or lignite. The woody fibres are cut through by the section transversely to their long axis.

Fig. 4.—Horizontal section of Bovey coal, or English lignite. The vegetable tissue is considerably broken up by the irregular distension of the circular spaces, dots, or discs of the coniferous woody tissue, some of which have thus been made into one cavity filled with the yellowish-red substance. The deposit of carbon matter has also commenced, and may be seen filling the centres of some of the discs, and generally the interspaces and walls of the cells and fibres.

Fig. 5.—Transverse section of Bovey coal, or lignite of England. Irregular distension of the circular spaces by the amber-coloured brown matter. Homologation of the vegetable tissue with the deposit of carbon and yellow matter.

Fig. 6.—Section from Torbane Hill cannel or gas coal, with preserved or uncoalified vegetable tissue of the scalariform kind. This specimen prepared by Dr. Aitken was in the possession of Dr. Balfour, Professor of Botany in Edinburgh.

Fig. 7.—Section of cannel coal from New Battle, in Midlothian, drawn from a specimen cut by the late Mr. Sanderson, of Edinburgh. A stripe of uncoalified and tolerably preserved vegetable structure is seen crossing the centre of the section; the upper and lower portion of this stripe have become a homogeneous brown mass, in which no remains of structure can be detected, and towards the uppermost and lowermost parts of the section it gradually passes into the characteristic structure of gas or cannel coal (magnified about 30).

Fig. 8.—Section of cannel coal from A. Pritchard, Fleet Street, London. The transition state in the process of hystolysis of the vegetable tissue is distinctly traceable; and the preserved or uncoalified vegetation is seen to pass by insensible gradations into the structure of cannel coal.

[To Binder.—*This leaf is to be placed between the Plates to which it refers.*]

PLATE B. (II.)

Fig. 1.—Amorphous or homogeneous gas-coal structure, from the Nova Scotia gas-coal.

Fig. 2.—Amorphous or homogeneous gas-coal substance from Pelton.

Fig. 3.—Horizontal section of Cowan's Newcastle cannel coal, composed of irregular masses of yellow matter amongst opaque carbon-like matter.

Fig. 4.—Longitudinal section of Glasgow splint coal, presenting in some places a minutely stratified appearance, in which large spaces of very irregular forms exist filled with the reddish-yellow matter.

Fig. 5.—Structure of coalified jet from the Wylam Colliery, Durham. It is minutely stratified, but irregular elongated spaces of a convoluted form exist in great abundance, filled with the reddish-yellow matter (prepared by the late Mr. Sanderson).

Fig. 6.—Section of cannel coal from the bottom part of the Wigan seam. The appearances were similar in whatever direction the specimen was cut. The bodies resembling spores are seen.

Fig. 7.—Lateral view of a section through the edges of the planes of stratification. A section across these planes was nearly similar.

Fig. 8.—Wigan cannel from the middle part of the seam looking down on the faces of the planes of stratification.

Fig. 9.—Lateral view of a section through the edges of the planes of stratification from the middle part of the seam.

Fig. 10.—Wigan cannel, top part of the seam, looking down on the faces of the planes of stratification.

STRUCTURE OF COAL.

Fig. 1.

Fig. 2.

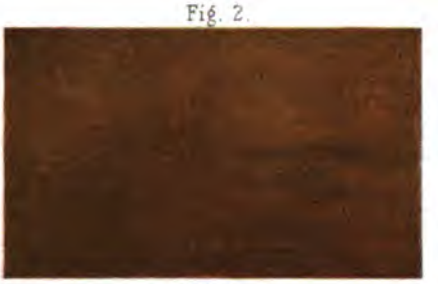


Fig. 3.

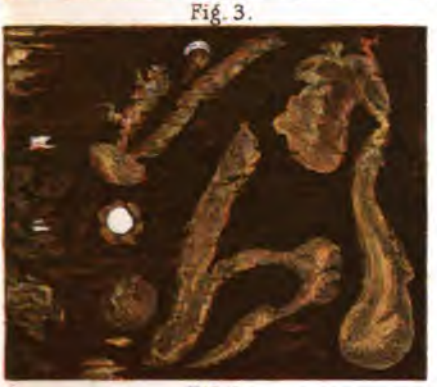


Fig. 4.

Fig. 5.

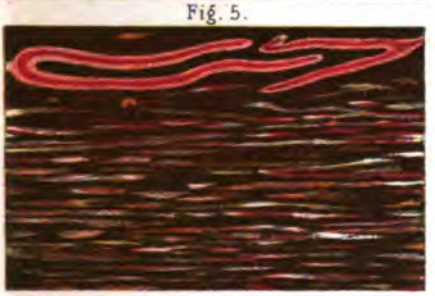


Fig. 6.

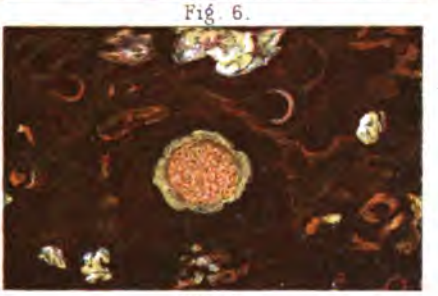


Fig. 7.

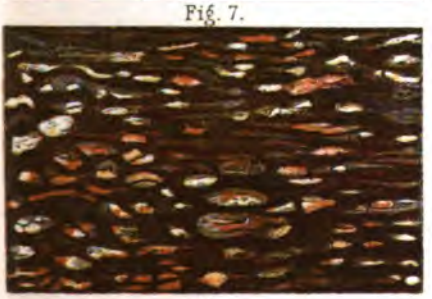


Fig. 8.

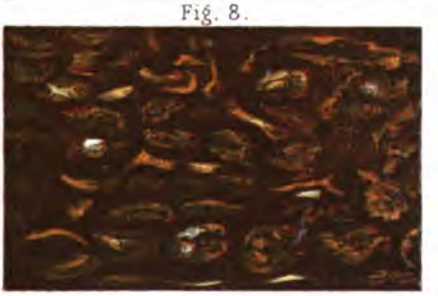


Fig. 9.

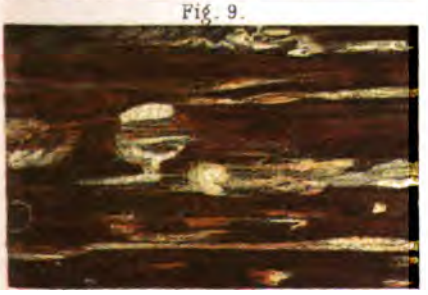
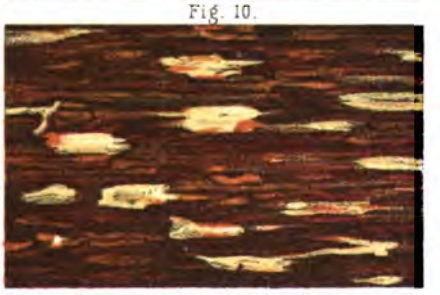


Fig. 10.



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tion to the antiseptic nature of the products of their decomposition. Their remains are often found forming the mineral charcoal, the mother coal or Faserkohlen of the Germans. Hatchett has noticed the same fact, and found that resin, next to woody fibre, most powerfully resisted all changes.

II. *Coal.*—When sections of the varieties of this substance are made and reduced to a uniform degree of thinness, so that if transparent they may be examined with transmitted light, with powers magnifying from 70 to 300 diameters, they will be found to present certain fixed and general features characteristic of some one of the particular class already named.

The great bulk of the household coals, including all the coking varieties, the anthracite and steam coals, are quite opaque throughout their substance, and can only be observed by reflected light.

The gas coals, such as the Pelton, the Nova Scotia, with the cannels, brown coals, jet and lignites, are all more or less transparent, and hence microscopically there are only two varieties of coaly substance—viz., *the opaque* and *partially transparent.*

A transparent microscopic section of coal is seen to be composed of three very obviously distinct materials, differing in appearance and properties. (See Figs. 6, 7, 8, Plate A; and Figs. on Plate B.) These materials are—

1. An opaque black substance.
2. A yellow or reddish substance.
3. An earthy matter sometimes more or less coloured.

The relative proportions in which these substances are associated evidently influence the various products derived from them. This is very obvious when the microscopic appearance is contrasted with the chemical constitution, and more especially with the gaseous and liquid products of their distillation, and which would appear to be peculiarly dependent upon the yellow or reddish coloured substances.

The black substance corresponds microscopically in appearance, and in reaction, with carbon as it is known to exist in the granular or amorphous state in various mineral substances in nature. It is insoluble in sulphuric and hydrochloric acids, and in dilute nitric acid, in caustic ammonia and potash, and chlorine is without any action on the colour.

The third body named, the earthy matter, is more or less soluble in water, to which it sometimes communicates a colour, and consists chiefly of the substance known as umber.

The nature of the second substance is not so easily ascertained. Its colour varies from a light yellow to a bright red or amber-coloured resinous-looking matter. It is volatilized by heat, and insoluble in oil of tar, naphtha, hydrochloric acid, and nitric acid. When free, bitumen is present; it colours the naphtha.

It may be generally stated that the black matter forms the chief and almost exclusive constituent of household and anthracite coals, whilst the yellow matter, on the contrary, enters most abundantly into the structure of gas coal. It is also worthy of observation that the external blackness of the coal is no criterion of the presence or absence of the yellow matter, as shown by the investigation of the nature and properties of the Pelton, Nova Scotia, Boghead, Wigan, Rochsoles, and similar gas coals. All the varieties of coal may therefore be classed into—

I. Coal substances whose sections are for the most part opaque, and abounding in black matter of the purest kind, including the steam, coking, household, and anthracite coals. (Compare Plate B.)

The coals from the low and high main seams of Newcastle Carr's steam coal, and Cowen's coking coal, may be particularly noticed as of the purest black description, and perfectly opaque in the thinnest slices. The coal of the Hutton Seam, a sample from Mr. Clark, of Walker Colliery, the Ebbvale

steam coal, the coking and anthracite coal of Pyle, Glamorganshire, and the household coal of Rhymney, belong to the same microscopic class.

II. Coals more or less transparent, comprehending—

1. Gas coals with a clear shining lustre, brittle and crystalline, as Nova Scotia, Pelton, &c.
2. Cannels, as Peace's Wigan, Cowen's cannel, Lesmahago, &c.
3. Coal variously stratified with earthy and black opaque coaly matter, such as splint.

III. Brown coals, or lignites, Bovey-coal, jet, &c.

Perhaps there is no fact more strongly brought out by recent investigations than the impossibility of comparing specimens of coal from the above classes with each other. Thus, for example, the common domestic coals are so black and opaque that it is impossible to make out any structure to which a reference could be made as characteristic of the class; in Cowen's Garesfield coal no yellow matter can be distinguished, while in that from Marley Hill the texture is a homogeneous mixture of yellow and black particles; but no transparent section can be made, and the above observation results from an examination of the powder and edge of the specimen. The only specimen of this class which presented any evidence of vegetable remains was Cowen's coking coal already mentioned. The structure seemed to present transverse sections of woody fibre. It was characterized by clear white regular spaces, with very dark bounding walls imbedded in a very dark molecular matrix, perfectly opaque. The arrangement of the preserved tissue was in a direction oblique to the stratification of the coaly substance. The general conclusion is that coal, according to the class examined, has a structure peculiar to itself, but that coal from the same class does not always present a uniform appearance in the mass, to the naked eye, as remains of fibres or forms of plants are sometimes found enclosed in its substance.

Among the early investigators of coal, no one has paid more attention to this part of the subject than Goepert, who regards coal with a well-preserved structure as imperfectly mineralized, or not perfectly transformed into coal: a conclusion supported in some measure by Witham, and confirming our remarks. This view is also adopted by Binney, who states that he has only once seen the vascular system perfectly preserved with iron pyrites in a specimen of the *King* coal of Wigan.

The wood-like tissue seen in the coal-seams exactly resembles charcoal: it is termed "mother-" or "father-coal" by the Germans. If the coal is highly bituminous, it is so rapidly consumed that all appearance of texture is destroyed; but specimens may be prepared for examination by the microscope in the following manner, as proposed by Schulz and Ehrenberg:—

"A piece of coal about 2 inches square is to be taken and broken into about twelve pieces of nearly the same size, and treated with nitric acid in a platinum crucible. The nitric acid is to be evaporated at a moderate heat, and the residue ignited till no further empyreumatic vapours are given off: treat the residue again with nitric acid, and repeat the ignition.

"Thus prepared, let the coal be placed in a platinum crucible, with a lid perforated in the centre, and blow air from a gasometer through the aperture in the lid, while the crucible is kept at a red heat over a spirit-lamp.

"The object of this is that the combustion of the coal may be as slow as possible. The ash obtained ought not to cake, but should form a brownish powder. Some white splinters occur among this ash, which appear, on microscopic examination, to be aggregated siliceous cells, arranged in regular succession, and of the structure of the prosenchymatous cells of wood."

As regards the ashes of the coaly substance, the observations of Lyell, Bailey, Hooker, Goepert, and others show how difficult it is to see remains

of vegetable structure in them, even when carefully prepared, and selected pieces are taken and decarbonized by the aid of nitric acid and heat.

Sir C. Lyell has noticed organic structure in the coal of Eastern Virginia, which he considers to have been derived from the vegetation of the ancient carboniferous period. Hooker examined some charcoal-like portions of this coal, and found a total absence of cellular and scalariform tissue, and thought that the structure was not referable to ferns. He found a fibrous texture, but the prominent glands were much more minute than those of coniferous wood, while the large perforated tubes were foreign to that order. The tissues consisted of parallel fibres or elongated cells, among which were very large tubes whose walls were pierced with circular or longitudinally or transversely elongated holes, either scattered or placed closely together.

The microscopic tissues found preserved in the substance of coal consist of portions of vascular tissue, such as woody fibres or scalariform tissue, with cellular tissue of various kinds,—portions of the organs of reproduction, such as seeds of plants of a microscopic size, like the spores or minute seeds of ferns.

Dr. Aitken was the first to detect the spores of ferns in the substance of coal, and has found them in clusters in Boghead, Capeldrae, and other coal.

In Class II. the Nova Scotia and Pelton coals are both amorphous or homogeneous in their thinnest sections, but the granular black matter exists in a greater proportion in the latter. The yellow matter of the Nova Scotia coal is soluble in ether, and slightly so in turpentine and nitric acid. The solution proceeds very gradually, and leaves the black matter unchanged. The same action takes place in the Pelton coal, but much more rapidly, and a portion of its yellow matter is soluble in water. These features are, however, more strongly developed in the cannel coals, and were first noticed by Hutton, who described them to the London Geological Society in 1832–33. The cells or spaces which he noticed and attributed to the distension produced by gas confined in a somewhat yielding material, are generally of a yellow resinous-like aspect, and may be described as areolar, while the black matter forms as it were the skeleton or network of the coal. These areolar spaces hold a definite relation to the stratification of the coal, and agree generally with what we know of stratified rocks. This is so characteristic of cannel and splint coals, that they may be described microscopically as "stratified coals."

Geological occurrence of Coal.—The greater number of coal-beds exhibit cleavages which take place in two constant directions,—one being parallel, or nearly so, to the plane of stratification, and the other perpendicular, thus forming an acute angle: hence the coals work or break in masses of a cubicular rhomboidal form. The distortion and flattening of the vegetable remains, and the facility with which the cleavage takes place, has generally some relation to the direction of greatest pressure. The enclosure of the yellow matter in areolar spaces bears, as might be expected, a definite arrangement in the direction of the cleavage. The spaces are flatter and broader as they lie upon the plane of horizontal cleavage, or in the direction of the line of stratification, while they are more elongated in section when examined along the edges of that plane, or along the dip of the cleavage. They vary most in sections taken "across the bed." Messrs. Quekett and Witham describe certain appearances of coal which have led them to regard a section of cannel coal as similar to a section of wood; but Dr. Aitken considers that these are connected with the phenomena of stratification and cleavage.

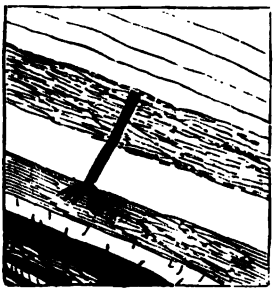
The stratified appearance seen in cannel and other coals has evidently been produced subsequently to the deposit of the material from which the coal has been produced.

Cracks and seams pass in definite directions through the beds of coals. When the stem of an entire tree, such as a sigillaria, is found erect, the

stratified arrangement, as seen in the bed of coal, passes continuously through the substance of the tree when it is coalified, penetrating the stem across the position of its longitudinal fibres. This fact is of great importance in reference to the structure of coal compared with wood, for such an appearance has no similarity to a parallel arrangement of the bundles of woody fibre. Perhaps the most remarkable instance of this kind is that described by Mr. Dawson in the coal measures of Nova Scotia.

In a thick bed of bituminous limestone, and in the midst of Moriday shale, is a very curious collection of upright plants. A tree, converted into coal, springs from the surface of the shale, and passes through 14 feet of sandstone and shale. On the surface of a bed of clay, 8 feet above the main coal, stands another upright tree, which is converted into hard shining coal, and passes through beds of sandstone and arenaceous shale to a height of 15 feet. Its roots, which are in a state of coal, spread in an irregular manner through the clay. He found very indistinct traces of cellular tissue in the mass, which consisted of compact coal divided by transverse joints, and an immense number of minute vertical cracks, with a few larger fissures which seemed to have a concentric arrangement.

Fig. 1.



The lignites, &c., in Class III., as shown in the Bovey coal (see Figs. 2, 3, 4, and 5, Plate B), exhibit a series of gradations from the most perfect ligneous texture to a substance possessing all the characters of cannel coal; the reverse of this is sometimes seen in splint coal, where instances of transition from perfectly preserved wood to ordinary coaly structure occur.

The general and microscopic appearances seen in the lignites, when compared with the cannel coals, and the whole viewed, as it were, in a series, show the actual transition of woody tissue into the coaly substance. In the three hundred specimens of bituminized woods in the German brown coal-fields, Goepert found chiefly coniferæ. The preservation of this species has been explained by supposing that the deciduous-leaved trees had lost their organic connection sooner than the highly resinous wood of the coniferæ, and thus become disintegrated.

The changes through which the vegetable matter has passed in its conversion into coal have evidently been suspended and only imperfectly carried on in the cases of German brown coal, Bovey coal, &c.

We have seen that characteristic microscopic appearances are associated with the predominance of the chemical properties peculiar to the black or carbonaceous, and the yellow, red, or volatile matter; and in the parts where tissue is preserved, as well as more particularly in the lignites, we can see that the tubes or cells have been distended unequally, and even broken up by the increase of yellow or red volatile matter, as is beautifully shown in one of Mr. Quekett's drawings.

The whole range of bitumens,—pure or unmixed, mineral tars, and asphaltum,—have no structure under the microscope, being homogeneous, and clear or brown-coloured.

Geologically, the brown coals or lignites are said to be of more recent formation, and in their varieties, when microscopically examined, the process of transformation is not found to have advanced so far as in cannel coal; but no very definite relation can be traced between the extent of the process of conversion and the geological antiquity of the species of coal.

In the drawings of the lignites (Plate B), the yellow material invariably occupies the spaces or cavities of cells or vessels, so that their texture becomes expanded, crushed, and broken up wherever it is found to exist.

The general conclusion confirms the first statement, that *coal is the product of decomposed or otherwise altered vegetable matter, associated with a variable amount of earthy substance, and capable of being used as fuel.**

The use of fossil fuel, which has had such a powerful influence on the history of modern times, is, even in England, a result of the scarcity of wood, and by no means very ancient.

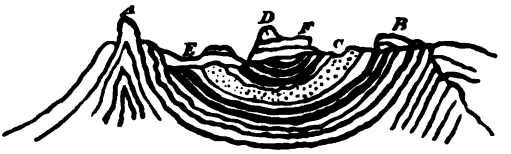
The ninth century is named by some authors as the period of the discovery of coal in England. In 1239 King Henry III. granted to the good men of Newcastle the privilege of digging coals, but it is not more than two hundred and fifty years since coal came into general use as a fuel in London, and at that period two ships were sufficient for carrying on the whole trade. A proclamation in the reign of Edward I., and another in the time of Elizabeth, prohibited the use of stone coal in London during the sitting of Parliament, lest the health of the knights of the shire should suffer during their residence in the metropolis; and shortly before 1649, the citizens of London are stated to have petitioned Parliament against two nuisances or offensive commodities which were likely to come into great use and esteem, and these were, "Newcastle coals, on account of their stench, &c., and hops, in regard they would spoyle the taste of drinck, and endanger the people."

Newcastle coal was first introduced in Paris in 1520. In the west of Scotland, the privilege of digging coal was granted to a religious house in 1291, but as early as A.D. 1200 collieries were being worked on the south shore of the Firth of Forth.† In Belgium, the earliest reference to mineral coal was in 1198 or 1200 in the county of Liége, where tradition ascribes its application as a fuel to a blacksmith.‡

According to Marco Polo, the Chinese were acquainted with coal as a fuel at a very early period.§

Coal is very much more abundant in the carboniferous and secondary, than in the tertiary formations; the deposits in the two former being, individually, much more extensive. It occurs in beds, or seams, sometimes called veins, interstratified with numerous other minerals, filling up what appear to have been hollows, or valleys, at the time of its deposition, and have frequently received the appellation of *coal basins*. The separate layers of coal and other minerals generally come to the surface, or *crop out* at the sides of these basins, defining thus the entire outward area of the formation.

FIG. 2.



The accompanying cut, Fig. 2, represents one of the basins belonging to the

* For further information upon the microscopic structure of coal, we may refer to the works and monographs of Decandolle, Brongniart, Lindley, Hutton, Hooker, Binney, Karsten, Nicol, Witham, Goepert, Corda, Teschmacher, Bennett, Quekett, Redfern, Greville, Balfour, and Fleming.

† See "Records of Early Mining in Scotland," by R. W. Cochran-Patrick, LL.D. (Edinburgh, 1878); and also "History of Coal Mining," by R. L. Galloway (London: Macmillan).

‡ "History of Fossil Fuel."

§ "In the Mountains of Cataja," as this distinguished traveller relates, "a kind of black stone is dug up, which laid upon the fire burns like wood, and when once ignited continues to burn for a long time, so that, if placed upon the fire in the evening, it will burn during the whole night. The stone when first ignited produces a small flame, like charcoal; it then continues to glow and gives off much heat."

Somersetshire and South Gloucestershire coal-fields. The elevations at *A* and *B* represent the old red sandstone formations of the Mendip Hills and Wick Rocks, the strong black lines the coal measures, and the others the rock with which they alternate—the lowest being mountain limestone; the next, millstone grit; whilst the dotted portion is Pennant grit rock, through which runs the river Avon, as indicated by the indentation at *C*. Above the higher beds of coal, the first horizontal stratum *E* consists of new red sandstone, upon which repose beds of lias *F*; the middle portion here, underlying the bifurcate section of Dundry Hill *D*, consisting of oolite; both these last-named are species of limestone, containing vast quantities of marine shells.

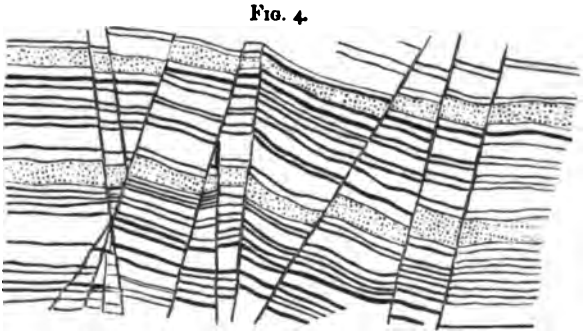
The Vale of Clyde, in the county of Lanark, the most valuable Scotch coal-field, is a vast basin, or trough, the strata composing which crop out at the surface, at variable distances, on both sides of the river. The South Wales coal-field, comprising an area of upwards of 900 miles, was supposed at one time to form a perfect basin, in the shape of a long-necked flask; but it has since been shown to be rather what is termed an inverted basin, the section, Fig. 3, presenting a rising of the measures on each side of the anticlinal axis *A*.

The basin-shape appears to have been the original one in all the coal-fields; but, in many instances, this has been subsequently modified by

Fig. 3.

powerful subterranean disturbances, producing slips, dykes, and dislocations. These *faults*, as they are sometimes called, consist of fissures, varying from a fraction of an inch to several yards in width, extending often for several miles, and to an undefined depth; on either side of them the strata have altered their relative positions, the rock having not only been rent asunder, but raised on the one side of the fissure, and depressed on the other, although it is impossible to ascertain on which side the elevation, depression, or rather the absolute motion, has occurred. The subjoined section, Fig. 4,

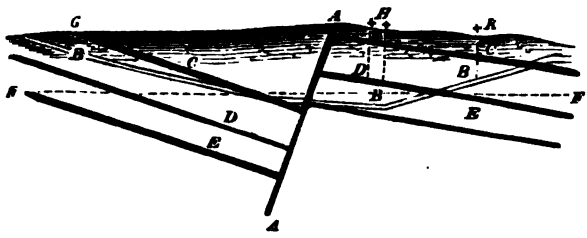
Fig. 4.



illustrates the manner in which the strata of the coal measures are dislocated, by faults in the neighbourhood of Jarrow, near Newcastle. Thus the same strata are found at different levels on opposite sides of these faults; the difference of level varying from a few inches to 500 feet, and in some instances to even 1,200 feet. The fissures are usually filled with clay, containing

fragments of the contiguous strata. Sometimes, however, basalt and other volcanic rocks appear to have entered them in a melted state from below, changing the nature of all the strata on which they impinge, and, of course, converting the coal, more or less, into coke.

Fig. 5.



The diagram, Fig. 5, exhibits a section of the great slip of the Northumberland and Durham coal-field, known as the great, or ninety-fathom dyke (*A A*), in consequence of the beds on the northern side being 90 fathoms lower than those on the southern side of it. The section is from a portion of a coal-field near Newcastle. This dyke is in some places 22 yards wide, and is filled with hard and soft sandstone. It is intersected by several other dykes, one of which is 70 yards wide, and by the whin dyke *B B B*, the central portion of which consists of basalt, 16 feet in thickness, and extends in an undulating course, underground, to a distance of about 11 miles. *C C* shows the high main coal; *D D*, the low main coal; *E E*, the Beaumont seam; *F F F*, level of the river Tyne; *H*, Benwell colliery; *K*, Newcastle town Moor.

A coal-basin always comprises a series of deposits of coal varying from two to sixty in number, and from a fraction of an inch to several feet in thickness; these are separated from each other by numerous strata, consisting chiefly of different varieties of sandstone, clay, and shale. Thus, in sinking a shaft at the Gosforth Colliery, about two miles north of Newcastle, the number of strata sunk through was as many as 142, the total depth being upwards of 188 fathoms. Forty-three seams of coal were pierced; many of them, however, were very thin, and incapable of being worked with profit. Much coal is worked about Newcastle at a depth of 400 feet, and it is generally observed that the thickness of the seam increases with the depth from the surface. The sandstone rock which covers the coal in the above locality is so massive that in some cases wooden supports are unnecessary in the workings. In the South Staffordshire coal-field, the main coal is about 60½ fathoms below the surface in the neighbourhood of Dudley, and is 10 yards in thickness; below it is another bed, 5 yards thick. At Gittersee, in the Valley of Plauen, near Dresden, there are seven beds, between which six thin layers of soft clay intervene.

Although it does not come within the province of this work to enter into details concerning the distribution or statistics of coal, yet the following general summary, taken from Mr. R. C. Taylor's "Statistics of Coal," may not be found uninteresting. The geographical distribution of coal in Europe and America is very unequal in the different countries. The following table shows the relative magnitude (1855) of the principal coal-producing countries, and respective areas of coal land, together with the proportions which they severally bear to each other. Those of France and Spain are considerably less than the actual amount; and Prussia, which is not included in the table, produces nearly as much coal as France.

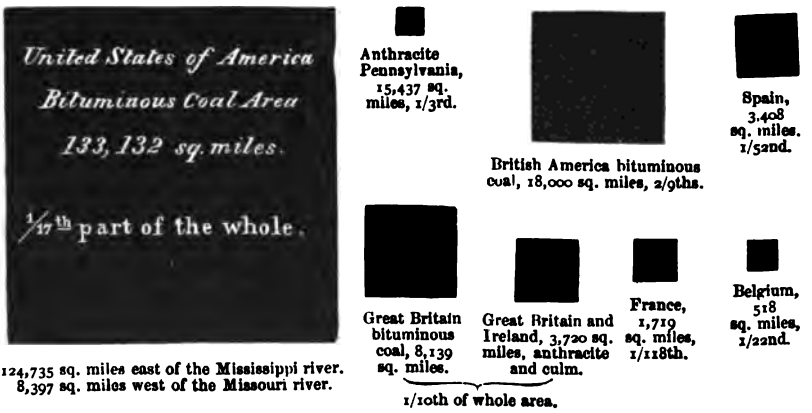
Countries.	Entire area of each country.	Area of coal land.	Proportion of coal land to the whole area.	Relative amounts of coal area per 1,000.
	Square miles, English.	Square miles.		
Great Britain and Ireland . . .	120,290	11,859	1—10	64
Spain (Asturias region)	177,781	3,408	1—52	18
France (area of fixed concessions) in 1845 .	203,736	1,719	1—118	9
Belgium, conceded lands	11,372	518	1—22	3
Pennsylvania, United States . . .	43,960	15,437	1—3	84
British Provinces: New Brunswick, Nova Scotia, Cape Breton, and Newfoundland .	81,113	18,000	1—4½	98
United States of America	2,280,000	—	1—17	—
The twelve principal coal-producing States	565,283	133,132	1—4	724
		184,073		1,000

Great Britain and Ireland, therefore, abound most in coal amongst European countries, whilst Belgium, as regards territorial proportion, comes second, although in relative coal area she is the least of the four. Pennsylvania possesses more coal land in proportion to its extent than any other country, although it is exceeded in actual quantity by the British provinces of North America. The area of coal in the United States is nearly three-fourths of the whole amount in the table.

The following diagram, perhaps, conveys at once a more accurate impression of the relative coal areas of the principal coal-producing countries, than the foregoing table; it is also borrowed from Mr. Taylor's work. These

FIG. 5A.

DIAGRAM OF THE SUPERFICIAL COAL AREAS OF VARIOUS COUNTRIES.


United States of America
Bituminous Coal Area
133,132 sq. miles.
1/17th part of the whole.
124,735 sq. miles east of the Mississippi river.
8,397 sq. miles west of the Missouri river.
Anthracite Pennsylvania, 15,437 sq. miles, 1/3rd.
British America bituminous coal, 18,000 sq. miles, 2/9ths.
Spain, 3,408 sq. miles. 1/52nd.
Great Britain bituminous coal, 8,139 sq. miles.
Great Britain and Ireland, 3,720 sq. miles, anthracite and culm.
1/10th of whole area.
France, 1,719 sq. miles, 1/118th.
Belgium, 518 sq. miles, 1/22nd.

tables, showing the relative areas of the coal districts in different countries, cannot be taken exactly as an index to the quantities of coal capable of being raised in the respective localities; as the number of seams of coal, their thickness, the ease with which they can be worked, their proximity to economical means of transport, and numerous other circumstances, must all influence, more or less, the productiveness of the mines, and the relative values of the produce. The following table exhibits the relative annual production, value of the coal, anthracite and lignite, in the six great coal-producing

countries of the globe, in the year 1845, from which time up to the present a regular increase has been simultaneously going on in all:—

Countries.	Square miles of coal formation.	Tons of fuel raised in 1845.	Relative parts of 1,000.	Official estimated value at the places of production.
Great Britain	11,859	31,500,000	642	9,450,000
Belgium	518	4,960,077	101	1,660,000
United States	133,132	4,400,000	89	1,373,963
France	1,719	4,141,617	84	1,603,106
Prussian States	Not defined	3,500,000	70	856,370
Austrian States	"	659,340	14	165,290
Total		49,161,034	1,000	15,108,729

The total quantities of coal raised in Great Britain in the years subsequent to 1840 were as follows:—

1840	34,026,108 tons	1874	124,937,925 tons
1845	31,500,000 "	1875	131,867,916 "
1850	44,612,271 "	1876	133,470,478 "
1855	64,453,079 "	1877	134,610,763 "
1860	80,042,698 "	1880	146,818,122 "
1865	98,150,587 "	1881	154,184,300 "
1870	109,035,284 "	1882	156,499,977 "
1871	117,352,028 "	1883	163,737,000 "
1872	123,492,050 "	1884	160,757,000 "
1873	127,016,747 "	1885	159,333,000 "

The number of miners employed was, in 1881, 501,000; and the value of the fuel raised, about £50,000,000. The total annual produce of the world is certainly not less than 300,000,000 tons.

According to Pechar, about 11 per cent. of the total British production is exported, the general distribution of the coal being somewhat as follows:—

Destination.	Per cent.
Iron manufacture	32.40
Factories	21.87
Dwelling-houses	16.36
Gas and water works	6.46
Mining	6.38
Steamers	6.46
Railways	1.76
Copper works	0.72
Sundries	0.64
Export	10.54

The numerous varieties of mineral coal have given rise to distinctions which are based partly on age, partly on appearance, and partly on quality. In most kinds of coal, the structure of the wood from which they have been formed is entirely obliterated; partial impressions of single parts of the plants alone indicate their origin. They form a compact deep-brown or perfectly black mass, sometimes dull, but generally having a fatty or vitreous lustre, and often exhibiting a play of colours; they present a finely granular fracture, not at all fibrous, and are much heavier than wood, bulk for bulk; they occur more or less stratified, and are nearly always fissured at right angles to the plane of stratification, in a manner similar to that which is observed when a doughy mass becomes dry. These fissures are often narrow, and first appear distinctly when the coals are broken up; but not unfrequently they are found open or filled with mineral substances, as iron

pyrites, calcareous spar, galena, dolomite, heavy spar, gypsum, clay, the soda-salts, and by a double carbonate of lime and iron. Independently of the want of connection in the coal mass, the causes of which have been referred to, the hardness and solidity of the coal are not very great. The fracture of the shining kinds of coal is conchoidal; of the other kinds it is even or hackly. Common coal, particularly that from more recent formations, is frequently accompanied by a small quantity of a kind of coal which can at once be distinguished from the great bulk by its colour and structure, and still more perceptibly by the difficulty with which it burns; it often appears in thin layers parallel with the plane of stratification, or is disseminated throughout the whole mass of the vein. This variety is often called *fibrous* or *fibre-coal;* it is richer in carbon, and consists of coal somewhat more advanced in the process of alteration than the other and larger portion, affording a striking exemplification of the change which is going on in all coal. The entire substance of coal, particularly that of the younger deposits, is observed to be made up of portions rich in carbon, along with others which are comparatively poor; it is a mixture, therefore, of coal in two stages of decomposition, of which the one is black, of a pitchy lustre and conchoidal fracture, the other dull, brown, and even. It might be thought, perhaps, that an unequal facility of decomposition in the different parts of the plants from which the coal is derived is the cause of this; but such a supposition is discountenanced by both stages occurring stratified, and in all manner of relations towards each other, from thin veins frequently alternating, to veins of several inches in thickness, fragments of these appearing to be homogeneous.

The varieties of pit coal, excluding the anthracites, are so very numerous, and pass so imperceptibly the one into the other, that many specimens can with difficulty be classified under any general denomination, or sub-species. The most marked physical varieties are those generally known in this country as *caking coal; splint*, or *hard coal; cherry*, or *soft coal;* and *cannel*, or *parrot coal.*

Caking Coal is velvet-black, or greyish-black, of a shining resinous lustre, and a small-grained or uneven fracture; when heated, it fuses together into a pasty cake, from which the bubbles of volatile matter escape as from a dough, leaving a coke of a totally different shape to the original coal. It soils the fingers, and breaks up into more or less cubical fragments; when ignited, it burns with a lively yellow flame, but requires frequent stirring in consequence of its caking property. It is inapplicable in many furnace operations in consequence of this peculiarity, and requires, when used for such purposes, to be previously converted into coke. Its composition will be seen from the tables in the following pages. The principal beds in the Newcastle coal-field are composed of this variety, as is also the sixth bed—reckoning from the surface—in the Glasgow coal-field; it is also abundant in other localities.

Splint, or **Hard Coal**, is black, with a shade of brown; it has a glistening resinous lustre, inferior to that of the cherry coal; the principal fracture is imperfect, curve slaty; the cross fracture is fine-grained, uneven, and splintery; it is not easily broken, hence one of its denominations. It is kindled with greater difficulty than either caking or cherry coal; but affords a lasting and clear fire, giving out much heat. This coal is very abundant amongst the Glasgow beds, and is the most highly prized.

Cherry, or Soft Coal.—This most abundant and beautiful variety is velvet-black in colour, with a slight intermixture of grey; it has a resplendent, or shining resinous lustre, whence it has derived its name of cherry from the miners. It does not cake when heated. The principal fracture is straight, slaty; different slates varying much in lustre. It is

very easily broken, and there is consequently much waste in mining it. It readily catches fire, but burns away much faster than other varieties. The greater part of the uppermost bed of the Glasgow coal-field and the Staffordshire coal belong to this species.

Cannel, or Parrot Coal.—Called *cannel* from its property of burning with a clear flame, like a candle, and *parrot* (in Scotland) from its property of flying off with a loud crackling sound when flat fragments are placed upon the top of a fire. This coal has a dark greyish-black or brownish colour, the lustre is glistening resinous, it takes a good polish, and can be made into inkstands, snuff-boxes, beads, and other ornaments; the fracture is flat conchoidal, frequently slaty. It does not soil the fingers, and does not break easily. It abounds at Lesmahagow near Glasgow, Wigan in Lancashire, and near Coventry in this country. Jet is only a variety of cannel coal.

The following tables give the composition of nearly all the varieties of cannel coal known in Great Britain, and of some other varieties which are used in the manufacture of gas:—

Name of Coal.	Specific Gravity.	Volatile Matter.	Coke.	Ash.	Ash in Coke. Per Cent.	Sulphur in		
						Coal.	Coke.	Volatile Matter.
Lochgelly Cannel	1.320	33.5	66.5	13.1	29.7	0.75	0.25	0.5
New Brunswick Cannel (Asphaltum)	1.098	66.3	33.7	0.6	1.78	0.7	—	0.7
Pelton Main	1.270	28.4	71.6	1.41	1.96	1.1	0.62	0.48
,, Cannel	1.320	31.5	68.5	9.4	13.7	0.95	0.49	0.46
Leverson's Wallsend	1.278	34.9	65.1	4.9	7.52	1.3	0.65	0.65
,, ,, Cannel	1.320	30.8	69.2	9.35	13.67	1.0	0.5	0.5
Washington	1.260	31.25	68.75	2.2	3.2	1.3	0.67	0.63
,, Cannel	1.326	27.4	72.6	9.37	12.9	1.1	0.56	0.55
Relaw Main	1.271	30.3	69.7	2.60	3.7	1.2	0.7	0.5
Urpeth	1.271	28.7	71.3	1.35	1.89	1.0	0.6	0.4
New Pelton	1.265	30.2	69.8	1.71	2.5	1.1	0.56	0.54
Dean's Primrose	1.261	29.25	70.75	2.4	3.4	1.4	0.71	0.69
Staveley (Derbyshire)	1.275	40.9	59.1	2.7	4.57	1.2	0.8	0.4
Elsecar Low Pit (Yorkshire)	1.258	37.0	63.0	1.1	1.74	1.2	0.63	0.57
Grigleston Cliff, soft ,,	1.255	35.6	64.4	1.6	2.48	1.4	0.75	0.65
Silkstone, No. 1 ,,	1.26	34.1	65.9	2.78	4.2	1.3	0.8	0.5
,, No. 2 ,,	1.259	38.0	62.0	2.55	4.1	1.1	0.6	0.5
,, No. 3 ,,	1.262	35.2	64.8	2.8	4.3	1.45	0.75	0.7
Arley (Lancashire)	1.270	33.7	66.3	3.6	4.8	1.2	0.6	0.6
Heathern (Staffordshire)	1.280	42.9	57.1	1.75	3.0	1.5	0.7	0.8
Coalpit Heath (Gloucestershire)	1.370	30.1	69.9	5.8	8.3	4.1	2.2	1.9
Radstock (Somersetshire)	1.275	38.25	61.75	3.5	5.6	3.1	1.8	1.3
Rhondda (S. Wales)	1.278	22.8	77.2	2.7	3.5	2.3	1.2	1.1
Denain (Valenciennes, France)	1.265	23.9	70.1	6.0	3.5	2.4	1.3	1.1
West Hartley	1.269	35.8	64.2	4.7	7.3	1.1	0.6	0.5
Hastings Hartley	1.278	36.5	63.4	2.0	3.1	0.95	0.5	0.45
Gosforth	1.260	35.0	65.0	1.0	1.5	1.1	0.5	0.6
South Pearth	1.266	27.8	72.2	1.8	2.5	1.2	0.6	0.6
Garesfield (Bute's)	1.290	28.3	71.7	3.2	4.4	0.9	0.4	0.5
,, (Cowan's)	1.259	29.4	70.6	0.95	1.3	0.85	0.4	0.45
South Tyne	1.339	36.3	63.7	3.9	6.1	2.1	1.1	1.0
Blenkinsopp	1.298	38.0	62.0	5.1	8.2	1.6	0.8	0.8
Woodthorpe (S. Yorkshire)	1.347	33.1	66.9	10.5	16.6	1.2	0.7	0.5
Soap House Pit ,,	1.258	35.0	65.0	0.8	1.2	0.75	0.4	0.35
Mortomly ,,	1.220	37.0	63.0	1.6	2.5	1.1	0.6	0.5
Cumberland, No. 1	1.294	25.5	74.5	2.1	2.8	1.3	0.7	0.6
,, No. 2	1.275	25.6	74.4	1.4	1.9	1.1	0.6	0.5
,, No. 3	1.290	30.9	69.1	4.0	5.8	1.7	0.8	0.9
Ruabon, Nant Seam (N. Wales)	1.269	37.9	62.1	1.4	2.2	1.1	0.7	0.4
,, Top Yard Seam ,,	1.269	37.5	62.5	2.5	4.0	1.4	0.8	0.6
,, Main Coal ,,	1.284	41.5	58.5	1.0	1.7	0.85	0.45	0.4
,, Yard Seam ,,	1.271	34.0	66.0	1.4	2.1	1.1	0.6	0.5
Rhondda Low Main (S. Wales)	1.280	23.1	76.9	2.1	2.7	2.2	1.1	1.1
Nailsea (Somersetshire)	1.312	34.9	65.1	3.0	4.6	2.85	1.5	1.35
Silverdale, 10 feet (N. Stafford)	1.301	34.0	66.0	1.95	2.92	1.3	0.7	0.6
Woodshutts, 7 feet, Banbury (N. Stafford)	1.291	40.2	59.8	1.22	2.03	0.9	0.54	0.36
Apedale (N. Stafford)	1.307	38.5	61.5	1.9	3.1	1.5	0.82	0.68
,, 4 feet ,,	1.267	40.0	60.0	0.75	1.25	0.80	0.38	0.42
Harecastle (Cheshire)	1.230	31.5	68.5	5.0	7.3	2.1	1.1	1.0
St. Helens (S. Lancashire)	1.285	37.2	62.8	1.2	1.91	1.1	0.54	0.56
Staffordshire Cannel	1.220	50.0	50.0	2.9	5.8	1.3	0.52	0.78
Whitecroit, near Lydney (Gloucestershire)	1.401	34.3	65.7	11.1	16.8	3.1	1.9	1.2

Cannel or Parrot Coals.	Coal.						Coke.		
	Specific Gravity.	Volatile Matters. Per Cent.	Fixed Carbon. Per Cent.	Ash. Per Cent.	Sulphur. Per Cent.	Water. Per Cent.	Total Amount of Coke in Coal. Per Cent.	Carbon in Coke. Per Cent.	Ash in Coke. Per Cent.
Rochsoles	1.448	53.7	4.9	38.8	1.6	1.	42.3	11.58	88.42
Hardie's	1.420	34.	4.	58.4	—	3.5	62.4	6.44	93.56
Boghead, Brown	1.160	71.06	7.10	26.2	.24	.4	28.3	25.09	74.91
„ Black	1.2185	62.7	9.25	26.5	.35	1.2	35.75	25.88	74.12
Torbanehill	1.1892	67.11	10.52	21.	.32	1.05	31.52	33.38	66.62
Boghead	1.1550	71.3	11.3	16.8	.34	.6	28.1	40.22	59.78
Bathville	1.201	64.35	12.6	22.2	.25	.60	34.80	36.21	63.79
Stan (Ayrshire)	1.4647	52.08	14.77	32.	—	1.15	46.77	31.52	68.48
Methill	1.3002	49.23	17.57	29.7	—	3.50	47.27	37.17	62.83
Capeldrae	1.3603	45.73	19.97	31.5	—	2.80	51.47	38.80	61.20
Wemyss	1.1831	58.52	25.28	14.25	—	1.95	39.53	63.95	36.05
Balhardie	1.420	38.96	29.66	28.	.38	3.0	57.66	48.56	51.44
Hillhead (Kilmarnock)	1.602 / 1.320	36.65	32.34	27.4	.61	3.	59.74	54.14	45.86
Brymbo	—	32.10	36.4	29.4	—	2.1	65.80	55.32	44.68
Lesmahagow (Auchinheath)	1.1990	56.23	36.7	4.3	.55	3.15	41.	89.50	10.50
Bartoushill	1.280	48.	39.6	10.	2.	2.4	49.6	79.84	20.16
„	1.350	38.	37.9	18.7	2.2	3.2	56.6	66.96	33.04
Stevenston (Ayrshire)	1.385	40.21	40.14	19.35	—	.3	59.49	67.64	32.36
Lesmahagow (Southfield)	1.228	49.34	40.97	6.34	1.35	2.	47.31	86.60	13.40
Knightswood	1.234	44.77	41 13	11.05	—	3.05	52.18	78.83	21.17
Cairnbroe	1.247	42 83	42.67	8.50	—	6.	51.17	83.39	26.61
Skaterigg	1.252	49.32	44.83	2.50	—	3.35	47.33	94.42	5.58
Cowdenhill	1.299	46.0	45.	5.	.50	3.50	50.	90.	10.
Bredisholme	1.335	39.	48.5	8.1	.4	4.	56.6	85.69	14.31
Ruchill	1.223	45.73	49.27	2.5	—	2.5	51.77	95.17	4.83
Kelvinside	1.231	40.17	53.42	1.9	.21	4.3	55.32	96.57	3.43

TABLE SHOWING NATURE OF THE ASH OF CANNEL COALS AND SHALES.

Locality.	Specific Gravity.	Volatile Matter.	Fixed Carbon.	Ash.	Composition of Ash.
Kirkness	1.208	60.	40.	13.5	Silicate of alumina and oxide of iron.
Old Wemyss	1.325	52.5	47.5	15 1	Ditto.
Knightswood	—	48.5	51.5	2.4	Oxide of iron and silicate of lime with alumina.
Armiston	1.196	45.5	54.5	4.18	Ditto.
Wigan	1.271	37.0	63.0	3.0	Oxide of iron and silicate of alumina.
Ramsey's Newcastle	1.290	36.8	63.2	6.6	Oxide of iron and silicate of lime with alumina.
Boghead Coal (Mean of 3 experiments)	1.209	69.70	7.73	22.57	Silica 69 %. Alumina, oxide of iron, lime, magnesia, &c., 31 %.
Lesmahagow Parrot Coal, Mean	1.230	51.44	39.57	8.98	Silica 48 %. Alumina, &c., 52 %.
Capeldrae „ „	1.321	50.00	33.90	16.10	„ 53 % „ 47 %.
Balhardie „ „	1.443	52.05	21.28	26.67	„ 70 % „ 30 %.
Methill „ „	1.147	69.43	21.84	8.72	
Rochsoles „ „	1.161	70.59	13.14	16.27	
Fife „ „ No. 1	1.430	45.50	32.55	21.95	
„ „ „ No. 2	1.327	46.56	39.55	13.89	
Cherry Coal from Torbanehill Parrot	—	42.16	40.90	16.94	Silica 65 %. Alumina 35 %.
Torbanehill, top of House Coal	1.327	32.27	64.80	2.92	
„ bottom „	1.401	28.11	42.22	27.28	Silica 78 %. Alumina 22 %.
Shale from Stirlingshire Coalfield	2.344	16.53	—	83.47	Silica 78 %. Alumina 22 %.
Birtledean Shale, Lancashire	2.390	16.84	—	83.16	„ 82 %. „ 18 %.
Pendleton	2.642	22.52	—	77.47	
Fife "Rums"	1.694	26.74	20.51	52.75	

The foregoing analyses show that cannel coals yield, on distillation, a very much larger amount of volatile matter, less coke, a larger quantity of ash, and generally more sulphur than the so-called bituminous class.

Anthracite is not compared in these tables on account of its yielding little or no volatile matter.

The ash of the cannels will be found to consist chiefly of silicate of alumina, and has been observed to bear a remarkable analogy to decomposed felspar from which a portion of silicate of potash has been washed out. This, when considered in connection with the large relative amount of ash in cannels, has suggested the inference that these varieties have been formed by the decomposition of an accumulation of the lower order of vegetables, such as mosses, lichens, sea-weed, &c., deposited with the débris of the older rocks, whilst the occurrence of ammonic chloride, and occasionally of compounds of iodine as observed by M. Bussy in the coal and products of distillation, points to a marine origin of the vegetable remains, or to a submergence below the waters of the sea.

The ash of bituminous coal, on the other hand, consists generally of calcic silicate and sulphate with oxide of iron and some argillaceous matter, the greater portion of which may have formed the natural ash of the large trees to which the formation owes its origin, and which are known to belong to a class (*Equisetaceæ*) yielding a silicious ash.

Sulphur is, with some marked exceptions, generally found in larger quantity in the cannels than in the bituminous coals, and a larger portion passes off with the volatile ingredients on distillation, partly in the form of sulphuretted hydrogen, but more as bisulphide of carbon. This fact has led to the conclusion that the sulphur in cannel coal is not derived exclusively from iron pyrites, as in bituminous coal, but exists in some other form of combination, from which it is evolved at a lower temperature, and is thus enabled to enter more readily into combination with carbon. Bituminous coal is never entirely free from iron pyrites or ferrous sulphide, and this, in presence of water and a high temperature, is decomposed, forming, with the elements of water, ferric oxide and sulphuretted hydrogen. Calcic carbonate frequently accompanies the layers of coal, forming thin bands between the seams; and at a high temperature, in a retort, this is decomposed, the carbonic acid being driven off and the calcium entering into combination with the sulphur, which it fixes so that a less quantity of sulphur escapes in the form of gas. Cannel coal is superior to all other kinds in the proportion of volatile matter which it yields.

In the trade, a great variety of appellations for coal are current, derived chiefly from the names of the pits where they are mined. These may afford some clue to the values of the coals amongst dealers and persons conversant with the trade, but are of no service to purchasers without some previous knowledge of the characters as deduced from experiment.

Compact masses of common coal of a pitchy lustre are called by some mineralogists *pitch coal;* more distinctly stratified kinds, splitting in a horizontal direction, *slate coal;* such as falls into very thin layers, *leaf coal;* and that which is dull and more massive, *coarse coal*, &c. The classification of coal according to the properties it exhibits when submitted to dry distillation will be noticed in describing the process of coking.

The specific gravity of bituminous coal varies from 1.2 to 1.5. Coal fresh from the pit, when exposed to the air, loses a portion of moisture without parting with the whole, retaining, according to its nature, from 1 to 12 per cent.; artificially dried coal re-absorbs hygroscopic moisture from the atmosphere.

Ash in Coal.—On an average, coal leaves less ash* than brown coal or turf, but, in consequence of the substances contained in its fissures, more than wood. On this point and the specific gravity of coal, the necessary information is contained in the following table:—

* See "Trans. Newcastle Chem. Soc.," vol. iv. pp. 135 and 140.

	Description and Locality of Coal.		Specific Gravity	Ash in 100 parts.	Observers.
Splint	Wylam Banks, Newcastle		1.302	13.912	Richardson
	Glasgow coal-field		1.307	1.128	
Cannel	Wigan, in Lancashire		1.319	2.545	
	Parrot coal, Edinburgh		1.318	14.566	
Cherry	Jarrow, Newcastle		1.266	1.676	
	Chief mass of coal from Glasgow		1.286	1.421	
Caking	Garesfield, Newcastle		1.280	1.393	
	South Hetton, Durham		1.274	1.519	
Coal measures	Alais, Rochebelle	fat and hard coal	1.322	1.41	Regnault
	Rive de Gier (P. Henry)	fat and hard coal	1.315	2.96	
	Flenû from Mons	fat coal, producing a long flame	1.276	2.10	
	" " "		1.292	3.68	
	Cimetière, Rive de Gier		1.288	3.57	
	" "		1.294	2.99	
	Couzon "		1.298	2.72	
	" "		1.311	5.32	
	Lavaysse		1.284	5.13	
	Epinac		1.353	2.53	
	Commentry		1.319	0.24	
	Blanzy	(dry coal, long flame)	1.362	2.28	
	Rive de Gier, Grand Croix	fat and hard	1.298	1.78	
	" "		1.302	1.44	
Secondary formation	Anthracite, Lamure, Dép. de l'Isère		1.362	4.57	
	" Macot		1.919	26.47	
	Common coal, Obernkirchen, Lippe-Sch.		1.279	1.0	
	Céral, Dép. Aveyron		1.294	11.86	
	Norov, Vogesen		1.410	19.20	
	St. Girons		1.316	4.08	
	Belestet		1.305	0.89	
	Czernitz, Upper Silesia		1.362	5.80	Karsten
	Gnade Gottes, Lower Silesia		1.285	4.65	
	Glück hülf " "		1.276	0.8	
	Sulzbach, Duttweiler, Saarbrücken		1.258	0.15	
	Wettin, Saalkreis		1.466	24.4	
	Sälzer and Neuack, Westphalia		1.288	0.7	
	Pottschappel, Saxony		1.454	27.7	
	Königin Louise, Upper Silesia		1.280	1.2	
	Königsgrube, " "		1.285	0.6	
	Merchweiler, Saarbrücken		1.282	0.9	
	Frischauf, Lower Silesia		1.518	23.4	
	Hundsnaker, Westphalia		1.338	0.6	
	Beata, Upper Silesia		1.383	11.9	
	Brazils		1.483	28.4	
	Coarse coal, mixed with Pitch coal		1.48	20.9	Lampadius
	Slate coal, " "		1.24	22.7	
	" with Fibre coal		1.20	26.3	
	Anthracite		1.37	22.5	
	Slate coal, with a little Fibre coal		1.25	20.2	
	Hard Slate coal, with layers of Pitch coal		1.42	24.0	
	Slate coal, with predominating layers of Anthracite and Fibre coal		1.35	23.4	

The mean specific gravity, therefore, of a coal with 8.73 per cent. of ash would appear to be = 1.33. If, however, those varieties containing an excessive amount between 19.20 and 28.4 per cent. of ash are not included in the calculation, a mean specific gravity of 1.30 will be obtained for coal containing on an average 5 per cent. of ash.

From the foregoing table, no direct connection between the specific gravity and the amount of ash contained in any specimen of coal can be deduced, although Professor Johnson believed that such was the case with coal from the same field, and considered the specific gravity as an index of the purity of coal. In analysing anthracites from Beaver Creek, Luzerne Co., he found in four varieties the following relative quantities of ash :—

	Sp. gr.	Ashes per cent.
1.	1.560	1.28
2.	1.594	4.00
3.	1.613	5.01
4.	1 630	5.063

In the coal from the basin of Maryland bordering on Pennsylvania, a similar result was observed :—

Mean specific gravity of two specimens.	Mean percentage of earthy matters in the two specimens.
1.32	7.52
1.35	9.58
1.365	10.35
1.385	11.75
1.485	14.41

From these results, it would seem that the specific gravity does increase in some cases with the amount of ash; but, as will be seen by the tables in subsequent pages, it is by no means a general fact.

The quantity of ash afforded by coal in a laboratory experiment frequently varies very considerably from that obtained from furnaces in actual work. Thus, it was found, by the experiments undertaken for the Admiralty Coal Investigation,* that the average amount of ash yielded in the laboratory from thirty specimens was . . . . . 5.76 per cent.
while the average afforded from the residues of the furnace was only . . . . . 4.62 „

leaving a difference, therefore, of . . . . . 1.14 „
or a less quantity by $\frac{1}{5}$ than by the laboratory operations. The explanation of this difference is due to the greater heat of the furnace leading to the volatilization of alkali in the draught, and probably also to the dissipation of some of the ash by the strong current passing through the furnace. In a few instances in this series of experiments, the reverse was observed to be the case; and in a large series of experiments undertaken by Johnson on American coal the reverse was also observed. Here the average amount of ash obtained by laboratory manipulation was . . 7.76 per cent.
that obtained from the residues of the furnace . . 9.10 „

showing a difference of . . . . . 1.34 „
in excess, or 17.27 per cent. more ash in the furnace than in the laboratory. It is obvious here that some of the carbon must have received a silicate glaze owing to a too rapid elevation of temperature in the furnace; in this way it would count as ash.

The greater proportion of ash contained in the American coal as compared with the British is probably due, in great measure, to the care which was taken to select the latter free from slaty matters, it having been usually mined expressly for the investigation; and these substances will find their way into commercial coals, when special care is not taken to prevent it. The amount of ash in several varieties of British coal will be found in the following tables showing the composition of coal.

The physical character of the ash of coal generally resembles that of brown coal; but its chemical composition depends much on local circumstances. In many varieties of coal-ash, silica and alumina predominate; in others, gypsum and oxide of iron due to pyrites, the latter being a highly injurious ingredient for most applications of the coal; besides these, the ashes contain oxide of iron, oxide of manganese, lime and magnesia in combination with carbonic acid, sometimes traces of lead and copper, phosphoric and

* Vide Tables at pages 53–56.

sulphuric acids, with small quantities of chlorine and iodine, although, rather strange to say, no alkali.

The ashes of seven varieties of bituminous coal have been analysed by Mr. J. A. Phillips, for the Admiralty Coal Investigation, with the following results:—

	Name of Coal.	Silica.	Alumina and Oxide of Iron.	Lime.	Magnesia.	Sulphuric Acid.	Phosphoric Acid.	Total per-centage.	Percentage of Ash in Coal.	Percentage of Coke in Coal.
Welsh	Pontypool	40.00	44.78	12.00	trace	2.22	0.75	99.75	5.52	64.8
	Bedwas	26.87	56.95	5.10	1.19	7.23	0.74	98.08	6.94	71.7
	Porthmawr	34.21	52.00	6.199	0.659	4.12	0.633	97.821	2.91	63.1
	Ebbw Vale	53.00	35.01	3.94	2.20	4.89	0.88	99.92	14.72	77.5
	Coleshill	59.27	29.09	6.02	1.35	3.84	0.40	99.97	10.70	—
Scotch	Fordell Splint	37.60	52.00	3.73	1.10	4.14	0.88	99.45	1.50	52.03
	Wallsend Elgin	61.66	24.42	2.62	1.73	8.38	1.18	99.99	4.0	58.45

The following partial analyses of the ash of some coals and anthracites have been published:—

Name of Coal.	Matter soluble in Water.	Matters insoluble in Water, soluble in Hydrochloric Acid	Matter insoluble in Acid and Water.	Total Amount of Ash in Coal per cent.	Experimenters.
Newcastle	7.0	36.5	56.5	2.04	Vaux
Wigan Cannel*	3.0	31.25	63.75	2.673	Vaux
St. Helen's	11.0	25.0	64.0	5.00	Vaux
Stafford	14.0	41.0	45.0	0.912 I. 2.76 II.	Vaux
Oregon	2.0	10.5	87.5	33.5	Vaux
Anthracite	5.7	25.7	68.6	1.583	Vaux
Mean of 5 specimens from Clay Cross, Staffordshire	12.462	49.946	37.592	2.807	Ronalds

Sulphur in Coal.—A mechanical admixture of iron pyrites is remarkable in all kinds of coal, and is exceedingly objectionable for many of its applications. In some kinds it may be seen in distinct crystals; in others it is so finely disseminated as only to be detected by chemical reagents. Sulphur also occurs organically combined in coal.

The volatile or organic portion of coal is composed of the same elements as wood, peat, and brown coal; their relative proportions, however, are different.

Nitrogen in Coal.†—Lunge ("Distillation of Coal Tar") gives the following statement of the average amount of nitrogen found by Dr. C. Meymott Tidy in various specimens of coal:—

Coal from	Nitrogen—per cent.
Wales	0.91
Lancashire	1.25
Newcastle	1.32
Scotland	1.44

The greater part, if not all, of this nitrogen is recoverable as ammonia under certain circumstances, and, in view of the enormous quantities of coal consumed in this country, the importance of this source of ammonia is being rapidly recognized.

* It was in the ash of these coals and those below that Mr. Vaux discovered traces of lead and copper.

† Refer also to W. Foster, "Jour. of Gas Lighting," 1882, vol. xl p. 1081, and "Jour. Chem. Soc." vol. xliii. Trans. 1883, 105, and "Min. Proc. Inst. C.E." vol. lxxvii. part iii.; Watson Smith, "Jour. Chem. Soc." vol. xlv. Trans. 1884, p. 144; Ramsay and Sidney Young, "Jour. Chem. Soc. Trans." 1884, p. 88; G. Beilby, "Chemical News," vol. xlvii. p. 221.

The following tables, showing the elementary composition of bituminous coal and some anthracites, are compiled from the results of recent experiments; in the first, the names of the observers are added, whilst the others are derived from the Admiralty Coal Investigation:*—

Description and Locality of Coal.		Carbon.	Hydrogen.	Oxygen. Nitrogen.	Observers.
Splint coal	Wylam Banks, Newcastle	74.823	6.180	5.085	Richardson
	Glasgow coal-field	82.924	6.491	10.457	
Cannel coal	Wigan, Lancashire	83.753	5.660	8.039	
	Parrot coal, Edinburgh	67.597	5.405	12.432	
Cherry coal	Jarrow, Newcastle	84.846	5.048	8.430	
	Chief coal from Glasgow	81.208	5.452	11.923	
Caking coal	Garesfield, Newcastle, Deep Bank	87.952	5 239	5.416	
	South Hetton, Durham	83.274	5.171	3.036	
Transition formation	Alais, Rochebelle	88.05	4.85	5.69	Regnault
	Corbeyre, Rive de Gier	86.65	4.99	5.49	
	Rive de Gier, Grand Croix, maréchal	86.25	5.14	6.83	
	" " raffaud	86.59	4.86	7.11	
	Flenû from Mons 1	83.51	5.29	9.10	
	" " " 2	82.72	5.42	8.18	
	Rive de Gier, Cimetière, bourrue	80.92	5.27	10.24	
	" " batarde	83.67	5.61	7.73	
	" Couzon, "	81.45	5.59	10.24	
	" " gr. masse	80.59	4 99	9.10	
	Decazeville, Dép. Aveyron, Lavaysse	81.00	5.27	8.60	
	Epinac	80.01	5.10	12.36	
	Commentry, Dép. l'Allier	81.59	5.29	12.88	
	Blanzy	75.43	5.23	17.06	
Secondary formation	Anthracite, Lamure, Dép. de l'Isère	88.54	1.67	5.22	
	Anthracite, from Macot	70.50	0.92	2.10	
	Obernkirchen, Lippe-Schaumburg	88.27	4.83	5.90	
	Céral, Dép. Aveyron	74.35	4.74	10.05	
	Noroy	62.41	4.35	14.04	
	Saint-Girons, jet	71.94	5 45	18.53	
	Belestat, jet	74.38	5.79	18.94	
	Leopoldinengrube, Upper Silesia	73.88	2.765	2.475	Karsten
	Königsgrube, from " "	78.39	3.21	17.77	
	Wellesweiler, Saarbrücken	81.32	3.21	14.47	
	Sälzer and Neuack, Westphalia	88.68	3.21	8.11	
	Eschweiler	89.18	0.44	2.94	
	Hundsnak, Westphalia	96.02	3.207	6.45	

MEAN COMPOSITION OF AVERAGE SAMPLES OF WELSH COALS.

Locality, or Name of Coal.	Specific Gravity of Coals.	Carbon.	Hydrogen.	Nitrogen.	Sulphur.	Oxygen.	Ash.	Percentage of Coke left by each Coal.
	A.	B.	C.	D.	E.	F.	G.	H.
Aberaman Merthyr	1.305	90.94	4.28	1.21	1.18	0.94	1.45	85.0
Ebbw Vale	1.275	89.78	5.15	2.16	1.02	0.39	1.50	77.5
Thomas's Merthyr	1.30	90.12	4.33	1.00	0.85	2.02	1.68	86.53

* With reference to the specimens for examination, Richardson classified his according to the plan adopted in England (Thomson) into Splint, Cannel, Cherry, and Caking coal; Regnault arranged his according to their geological age; and Karsten followed an arrangement of which we shall again speak presently. The transverse lines in the columns of numbers correspond with the respective divisions in a like order.

WELSH COALS—(*continued*).

Locality, or Name of Coal.	Specific Gravity of Coals.	Carbon.	Hydrogen.	Nitrogen.	Sulphur.	Oxygen.	Ash.	Percentage of Coke left by each Coal.
	A.	B.	C.	D.	E.	F.	G.	H.
Duffryn	1.326	88.26	4.66	1.45	1.77	0.60	3.26	84.3
Nixon's Merthyr	1.31	90.27	4.12	0 63	1.20	2.53	1.25	79 11
Binea	1.304	88.66	4.63	1.43	0 33	1.03	3.96	88.10
Bedwas	1.32	80.61	6 01	1.44	3.50	1.50	6.94	71.7
Hill's Plymouth Work	1.35	88.49	4.00	0.46	0.84	3.82	2.39	82.25
Aberdare Co.'s Merthyr	1.31	88.28	4.24	1.66	0 91	1.65	3.26	85.83
Gadly's Nine-feet Seam	1.33	86.18	4.31	1.09	0.87	2.21	5.34	86.54
Resolven	1.32	79.33	4.75	1.38	5.07	included in ash	9.41	83.9
Mynydd Newydd	1.31	84.71	5.76	1.56	1.21	3.52	3.24	74 8
Abercarn	1.334	81.26	6.31	.77	1.86	9.76	2.04	68.4
Anthracite, Jones & Co.	1.375	91.44	3.46	0 21	0.79	2.58	1.52	92.9
Ward's Fiery Vein	1.344	87.87	3.93	2.02	0.83	included in ash	7.04	—
Neath Abbey	1.31	89.04	5.05	1.07	1.60	—	3.55	61.42
Graigola	1.30	84.87	3.84	0.41	0.45	7.19	3.24	85.5
Gadly's Four-feet Seam	1.32	88.56	4.79	0 88	1.21	—	4.88	88.23
Machen Rock Vein	1.297	71.08	4.88	.95	1.37	17.87	3.85	65.2
Birch Grove, Graigola	1.360	84.25	4.15	.73	.86	5.58	4.43	85.1
Llynvi	1.28	87.18	5.06	0.86	1.33	2.53	3.04	72.94
Cadoxton	1.378	87.71	4.34	1.05	1.75	1.58	3.57	82.0
Oldcastle Fiery Vein	1.289	87 68	4.89	1.31	0.09	3.39	2.64	79.8
Vivian & Sons' Merthyr	1.299	82.75	5.31	1.04	.95	4.64	5.31	67.1
Llangennech	1.312	85.46	4.20	1.07	0.29	2.44	6.54	83.69
Three-quarter Rock Vein	1.34	75.15	4.93	1.07	2.85	5.04	10.96	62.5
Pentrepoth	1.31	88.72	4.50	0.18	—	3.24	3.36	82.5
Cwm Frood Rock Vein	1.255	82.25	5.84	1.11	1.22	3.58	6.00	68.8
Cwm Nant y Gros	1.28	78.36	5.59	1.86	3.01	5.58	5.60	65.6
Brymbo Main	1.300	77.87	5.09	.57	2.73	9.52	4.22	55.4
Vivian & Sons' Rock Vawr	1.301	79.09	5.20	.66	2.41	8.34	4.30	58.6
Coleshill	1.29	73.84	5.14	1.47	2.34	8.29	8.92	56.0
Brymbo Two-yard	1.283	78.13	5.53	.54	1.88	8.02	5.90	56 2
Rock Vawr	1.29	77.98	4.39	0.57	0.96	8.55	7.55	62.50
Porthmawr	1.39	74.70	4.79	1.28	0.91	3.60	14.72	63.1
Pontypool	1.32	80.70	5.66	1.35	2.39	4.38	5.52	64.8
Pentrefelin	1.358	85.52	3.72	trace	0.12	4 55	6.09	85.0

MEAN COMPOSITION OF AVERAGE SAMPLES OF NEWCASTLE COALS.

Locality, or Name of Coal.	Specific Gravity of Coals.	Carbon.	Hydrogen.	Nitrogen.	Sulphur.	Oxygen.	Ash.	Percentage of Coke left by each Coal.
	A.	B.	C.	D.	E.	F.	G.	H.
Willington	—	86.81	4.96	1.05	0.88	5.22	1.08	72 19
Andrews House, Tanfield	1.26	85.58	5.31	1.26	1.32	4.39	2.14	65.13
Bowden Close	—	84.92	4.53	0.96	0.65	6.66	2.28	69.69
Haswell Wallsend	1.286	83 47	6.68	1.42	.06	8.17	0.20	62.70
Newcastle Hartley	1.29	81.81	5.50	1.28	1.69	2.58	7.14	64.61
Hedley's Hartley	1.31	80.26	5.28	1.16	1.78	2.40	9.12	72.31
Bates' West Hartley	1.25	80.61	5.26	1.52	1.85	6.51	4.25	—
West Hartley Main	1.264	81.85	5.29	1.69	1.13	7.53	2.51	59.20
Buddle's West Hartley	1.23	80.75	5.04	1.46	1.04	7.86	3.85	—
Hastings' Hartley	1.25	82.24	5.42	1 61	1.35	6.44	2.94	35.60
Carr's Hartley	1.25	79.83	5.11	1.17	0.82	7.86	5.21	60.63
Davison's West Hartley	1.25	83.26	5.31	1.72	1.38	2.50	5.84	59.49
North Percy Hartley	1.25	80.03	5 08	0.98	0.78	9.91	3.22	57.18
Haswell Coal Co.'s Steamboat Wallsend	1.27	83.71	5.30	1.06	1.21	2.79	5.93	61.38

NEWCASTLE COALS—(*continued*).

Locality, or Name of Coal.	Specific Gravity of Coals.	Carbon.	Hydrogen.	Nitrogen.	Sulphur.	Oxygen.	Ash.	Percentage of Coke left by each Coal.
	A.	B.	C.	D.	E.	F.	G.	H.
Derwentwater Hartley	1.26	78.01	4 74	1.84	1.37	10.31	3.73	54.83
Broomhill	1.25	81.70	6.17	1.84	2.85	4.37	3.07	59.20
Original Hartley	1.25	81.18	5.56	0.72	1.44	8.03	3.07	58.22
Cowpen & Sidney's Hartley	1.26	82.20	5.10	1.69	0.71	7.97	2.33	58.59

MEAN COMPOSITION OF AVERAGE SAMPLES OF DERBYSHIRE COALS.

Locality, or Name of Coal.	Specific Gravity of Coals.	Carbon.	Hydrogen.	Nitrogen.	Sulphur.	Oxygen.	Ash.	Percentage of Coke left by each Coal.
	A.	B.	C.	D.	E.	F.	G.	H.
Earl Fitzwilliam's Elsecar	1.296	81.93	4.85	1.27	.91	8.58	2.46	61 6
Holyland & Co.'s Elsecar	1.317	80.05	4.93	1.24	1.06	8.99	3.73	62.5
Earl Fitzwilliam's Park Gate	1.311	80.07	4.92	2.15	1.11	9.95	1.80	61.7
Butterley Co.'s Portland	1.301	80 41	4.65	1.59	.86	11.26	1.23	60.9
Butterley Co.'s Langley	1.264	77.97	5.58	.80	1.14	9.86	4.65	54.9
Stavely	1.27	79.85	4.84	1.23	0.72	10.96	2.40	57.86
Loscoe Soft	1.285	77.49	4.86	1.64	1.30	12.41	2.30	52.8

MEAN COMPOSITION OF AVERAGE SAMPLES OF LANCASHIRE COALS.

Locality, or Name of Coal.	Specific Gravity of Coals.	Carbon.	Hydrogen.	Nitrogen.	Sulphur.	Oxygen.	Ash.	Percentage of Coke left by each Coal.
	A.	B.	C.	D.	E.	F.	G.	H.
Ince Hall Co.'s Arley	1.272	82.61	5.86	1.76	.80	7.44	1.53	64.0
Haydock Little Delf	1.257	79.71	5.16	.54	.52	10.65	3.42	58.1
Balcarres Arley	1.26	83.54	5.24	.98	1.05	5.87	3.32	62.89
Blackley Hurst	1.26	82.01	5.55	1.68	1.43	5.28	4.05	57.84
Ince Hall Pemberton Yard	1·348	80.78	6.23	1.30	1.82	7.53	2.34	60.6
Haydock Rushy Park	1.323	77.65	5.53	.50	1.73	10.91	3.68	59.4
Moss Hall Pemberton Four-feet	1.258	75.53	4.82	2.05	3.04	7.98	6.58	55.7
Haydock Higher Florida	1.218	77.33	5.56	1.01	1.03	12.02	3.05	51.1
Ince Hall Pemberton Four-feet	1.276	77.01	3.93	1.40	1.05	5.52	1.09	57.1
Blackbrook Little Delf	1.26	82.70	5.55	1.48	1.07	4.89	4.31	58.48
King	1.300	73.66	5.30	1.68	1.58	9.06	8.72	62.4
Rushy Park Mine	1.28	77.76	5.23	1.32	1.01	8.99	5.69	56.66
Blackbrook Rushy Park	1.27	81.16	5.99	1.35	1.62	7.20	2.68	58.10
Johnson & Wirthington's Rushy Park	1.28	79.50	5 15	1 21	2 71	9.24	2.19	57.52
Laffak Rushy Park	1.35	80.47	5.72	1.27	1.39	8.33	2.82	56.26
Balcarres Haigh Yard	1.28	82.26	5.47	1.25	1.48	5.64	3.90	66.09
Haydock Florida Main	1.267	77.49	5.50	1.27	.88	12.84	2.02	54.4
Wigan Four-feet	1.209	78.86	5.29	.86	1.19	9.57	4.23	60.0
Ince Hall Pemberton Five-feet	1.269	68.72	4.76	2.20	1.35	18.63	14.34	56.5
Cannel (Wigan)	1.23	79.23	6 08	1.18	1.43	7.24	4.84	60.33
Ince Hall Co.'s Furnace Vein	1.314	74.74	5.71	1.53	.96	13.52	4.04	58.4
Balcarres Lindsay	1.26	83.90	5.66	1.40	1.51	5.53	2.00	57.84
Caldwell & Thompson's Rushy Park	1.271	76.17	5.46	1.09	.91	14.87	1.50	58.7
Balcarres Five-feet	1.26	74.21	5 03	.77	2.09	8.69	9.21	55.90
Moss Hall Pemberton Five-feet	1.283	76 16	5.35	1.29	1.05	10.13	6.02	56.1
Moss Hall Co.'s New Mine	1.278	77.50	5.84	.98	1.36	12.16	3.16	57.7
Caldwell & Thompson's Higher Delf	1.274	75 40	4.83	1.41	2.43	19.98	5.95	54.2
Johnson & Wirthington's Sir John	1.31	72 86	4.98	1.07	1.54	8.15	11.40	56.15

MEAN COMPOSITION OF AVERAGE SAMPLES OF SCOTCH AND VARIOUS OTHER COALS.

	Locality, or Name of Coal.	Specific Gravity of Coals.	Carbon.	Hydrogen.	Nitrogen.	Sulphur.	Oxygen.	Ash.	Percentage of Coke left by each Coal.
		A.	B.	C.	D	E	F.	G.	H.
Scotch Coals	Wallsend Elgin	1 20	76.09	5.22	1.41	1.53	5.05	10.70	58.45
	Wellwood	1.27	81.36	6.28	1.53	1.57	6.37	2.89	59.15
	Dalkeith Coronation Seam	1.316	76.94	5.20	trace	0.38	14.37	3.10	53.5
	Kilmarnock Skerrington	1.241	79.82	5.82	.94	.86	11.31	1.25	49.3
	Fordel Splint	1.23	79.58	5.50	1.13	1.46	8.33	4.00	52.03
	Grangemouth	1.29	79.85	5.28	1.35	1.42	8.58	3.52	56.6
	Eglinton	1.25	80 08	6.50	1.55	1.38	8.05	2.44	54.94
Various	Dalkeith Jewel Seam	1.277	74.55	5.14	0.10	0.33	15.51	4.37	49 8
	Coleshill Co.'s Bagillt Main	1.269	88.48	5.62	2.02	1.36	0.86	1.62	55.8
	Ewlowe	1.275	80.97	4.96	1.10	1.40	8.20	3.37	54.5
	Ibstock	1.291	74.97	4.83	.88	1.45	11.88	5.99	50.8

AVERAGE COMPOSITION OF COALS FROM DIFFERENT LOCALITIES.

Locality.	Specific Gravity of Coal.	Carbon.	Hydrogen.	Nitrogen.	Sulphur.	Oxygen.	Ash.	Percentage of Coke left by each Coal.
verage of:	A.	B.	C.	D.	E.	F.	G.	H.
36 samples from Wales	1.315	83.78	4.79	0.98	1.43	4.15	4.91	72.60
18 ,, Newcastle	1.256	82.12	5.31	1.35	1.24	5.69	3.77	60.67
28 ,, Lancashire	1.273	77.90	5.32	1.30	1.44	9.53	4.88	60.22
8 ,, Scotland	1.259	78.53	5.61	1.00	1.11	9.69	4 03	54.22
7 ,, Derbyshire	1.292	79 68	4 94	1.41	1.01	10.28	2 65	59.32

AVERAGE COMPOSITION OF FOREIGN COALS.

	Locality.	Specific Gravity of Coal.	Carbon.	Hydrogen.	Nitrogen.	Sulphur.	Oxygen.	Ash.
		A.	B.	C.	D.	E.	F.	G.
Van Diemen's Land Coals	South Cape	—	63.40	2.89	1.27	0.98	1.01	30.45
	Mount Nicholas Break o' Day	—	57.37	3.91	1.15	0.90	9.10	27.55
	Tingal	—	57.21	3.38	1.20	1.32	7.80	29.09
	Jerusalem	—	68.18	3.99	1.62	1.12	5.89	19.20
	Douglas River, East Coast	—	70.44	4.20	1.11	0.70	9.27	14.38
	Tasman's Peninsula	—	65.54	3.36	1 91	1.03	1.75	26.41
	Schonten Island	—	64.01	3 55	0.94	0.85	3.38	27.17
	Whale's Head, South Cape	—	65.86	3.18	1.12	1.14	7 20	21.50
	Adventure Bay	—	80.22	3.05	1.36	1.90	4.80	8.67
	Sydney, New South Wales	—	82.39	5.32	1.23	0.70	8.32	2.04
	Borneo (Lahman kind)	1.28	64.52	4 74	0.80	1.45	20.75	7.74
	,, Three-feet Seam	1.37	54.31	5.03	0 98	1.14	24.22	14.32
	,, Eleven-feet Seam	1.21	70.33	5.41	0 67	1.17	19.19	3.23
	Formosa Island	1.24	78.26	5.70	0.64	0.49	10.95	3.96
	Vancouver's ,,	—	66.93	5.32	1.02	2.20	8.70	15.83
	Lignite, Trinidad	—	65.20	4.25	1.33	0.69	21.69	6.84
Chili Coals	Conception Bay	1.29	70.55	5.76	0.95	1.98	13.24	7 52
	Port Famine	—	64.18	5.33	0 50	1.03	22.75	6.21
	Chirique	—	38.98	4.01	0.58	6.14	13.38	36 91
	Laredo Bay	—	58.67	5.52	0.71	1.14	17.33	16.63
	Talcahnano Bay	—	70.71	6.44	1.08	0 94	13.95	6.92
	Colcurra Bay	—	78.30	5.50	1.09	1.06	8.37	5.68
Patagonia Coals	Sandy Bay, No. 1	—	62.25	5.05	0.63	1.13	17.54	13.40
	,, ,, No. 2	—	59.63	5.68	0 64	0.96	17.45	15.64

Some few elementary analyses of American coals have been furnished by Professor Johnson, which will be found in a table below, in connection with the relative value of fuel.

Although nitrogen is found in all kinds of coal (as shown in the last tables), yet no such intimate relation has been traced between it and the qualities of the coal, as is the case with the three other elementary constituents. The sulphur in coal is partly organic, partly in the form of calcic sulphate, and partly as pyrites. With the increase of carbon, the colour of the coal becomes of a darker brown until it is quite black, the lustre gradually rising from that of pitch to a vitreous hue. On the contrary, coal is harder when the amount of carbon is diminished, as in some varieties of cannel coal. The hardness has been said to depend on the relative proportions of hydrogen and oxygen, and to be augmented by an increase of the latter.

Anthracite.—The oldest of all kinds of fossil fuel, anthracite, belongs to the transition formation, and must be regarded as the last product of the mouldering process. Notwithstanding its similarity in outward appearance to other species of coal, it distinctly differs from them, both in composition, and by the manner in which it burns. The relation of anthracite to common coal is the same as that of the latter to brown coal. Certain kinds of coal, as those of Lamure and Macot in the table, are classed with the anthracites, on account of the similarity of their properties; these, however, are not the result of an advanced stage of the process of decay, but of the agency of heat accompanying the later elevations of primary rocks. Anthracite is eminently homogeneous and without impressions of plants; it is black, has a decidedly vitreous lustre, an iridescent play of colours, and a conchoidal, sharp-edged fracture. Its structure is massive. The amount of ash, composition, and specific gravity of specimens of this kind of coal are given in the next table.

Regnault found 0.37, Jacquelin 0.58 to 2.85 nitrogen. The ash consists of silica, alumina, and oxide of iron; and, according to more recent observations, it also contains chlorides, which, volatilizing during combustion, damage the metallic portions of the stove or grate in which such coal is used.

Locality of Anthracite.	Specific Gravity.	Carbon.	Hydrogen.	Oxygen. Nitrogen. Sulphur.	Ash.	Name of Observers.
Pennsylvania, America	1.462	89.21	2.43	3.69	4.67	Regnault
Wales, Swansea	1.348	91.29	2.33	4.80	1.58	Regnault
Mayenne, town and Dép. Mire Baconnière	1.343	90.20	4.18	3.37	2.25	Regnault
Rolduc, near Aix-la-Chapelle	1.367	90.72	3.92	4.42	0.94	Regnault
Swansea	1.270	90.58	3.60	4.10	1.72	Jacquelin
Sablé, Dép. de la Sarthe	1.750	87.22	2.49	3.39	6.90	Jacquelin
Vizille, Dép. de l'Isère	1.730	94.09	1.85	2.85	1.90	Jacquelin
Isère	1.650	94.00	1.49	3.58	4.00	Jacquelin
Wales, Jones & Co.	1.375	91.44	3.46	3.58	1.52 (Including O.)	Admiralty Coal Investigation
				N. | S.		
Slievardagh, Ireland	1.59	80.03	2·30	0.23 | 6.79	10.80	Admiralty Coal Investigation

Professor Johnson gives the following composition for the ash of some American anthracites:—

Characters and Ingredients of Ashes.	Sugarloaf Company's Anthracite, Hazle Creek. 1st specimen. Sp. gr. 1.591.	Sugarloaf Anthracite. 2nd specimen. Sp. gr. 1.574.	Sugarloaf Anthracite. 3rd specimen. Sp. gr. 1.55.	Buck Mountain Anthracite. Sp. gr. 1.559.	Summit Coal Company's Anthracite, head of Beaver Creek. 1st specimen. Sp. gr. 1.613.	Summit Company's Anthracite. 2nd specimen. Sp. gr. 1.594.	Stephenson's Bluff Anthracite, Beaver Creek. Sp. gr. 1.612.	Salem-vein Anthracite, Pottsville. Sp. gr. 1.569.	Quin's Run Bituminous Coal. Sp. gr. 1.372.
Percentage of ashes in the coal	4.83	8.73	2.242	3.079	5.01	4.00	3.71	6.75	6 80
Colour	Light-buff	Reddish-white	White	Reddish-buff	Fawn	Reddish-grey	Fawn	Brick-red	Grey
Silica	53.603	45.105	43.68	45.60	54.50	50.25	50.05	50.00	76.00
Alumina	36.687	37.000	39.34	42.75	34.45	38.90	39.04	38.90	21.00
Peroxide of iron	5.590	13.000	8.22	9.43	7.50	8.75	8.75	8.00	2.60
Lime	2.857	1.380	5 76	1.41	2.25	0.85	1.56	2 10	—
Magnesia	1.076	2.430	3.00	0.33	1.30	1.25	1.30	0.90	—
Oxide of manganese	0.186	—	—	—	—	—	—	—	—
Loss per cent.	—	1.085	—	—	—	—	—	—	0.40
Sum	99.999	100.000	100.00	99.52	100.00	100 00	100 70	99.90	100.00

From a careful examination of the composition of fossil fuel, as shown in the foregoing tables, it is evident that there is a gradual increase in carbon as compared with woody fibre, until at length the hydrogen and oxygen become less than 10 per cent. This circumstance becomes still more obvious, when the amount of ash is deducted, as in the following table:—

Description of the Substance.	Carbon.	Hydrogen.	Oxygen.
Woody fibre	52.65	5.25	42.10
Peat from Vulcaire	59.57	5 96	34.47
Lignite from Cologne	66.04	5.27	28.69
Earthy brown coal from Dax	73.18	5.88	21.14
Coal from Belestat, secondary	75.06	5.84	19.10
" Rive de Gier, Corbeyre, coal formation	89.29	5.05	5.66
Anthracite, Mayenne, transition formation	91.58	3 96	4.46

Another instance is given in the following series:—

PROGRESSIVE DIMINUTION OF H. AND O. IN SERIES FROM WOOD TO ANTHRACITE.

	Carbon.	Hydrogen.	Oxygen.	Disposable Hydrogen.
1. Wood (mean of several analyses)	100	12.18	83.07	1.80
2. Peat " "	100	9.85	55.67	2.89
3 Lignite (mean of 15 varieties)	100	8.37	42.42	3.07
4. Coal (Ten-yard coal, South Staffordshire)	100	6.12	21.23	3 47
5. Steam coal from Newcastle	100	5.91	18.32	3.62
6. Pentrefelin coal, South Wales	100	4.75	5.28	4.09
7. Anthracite from Pennsylvania	100	2.84	1.74	2.63

Finally, we quote the following evidence from Crookes and Röhrig's "Metallurgy":—

Substance.	Locality.	Authority.	Carbon.	Hydrogen.	Oxygen.	Nitrogen.
Pure woody fibre	—	Schödler	52.65	5.25	42.10	—
Beech	—	Chevandier	48.89	6.07	43.11	0.93
Oak	—	,,	50.64	6.03	42.05	1.28
Peat	Holland	Milder	59.27	5.41	35.32	—
,,	Long	Regnault	60.06	6.21	33.73	—
,,	Bog of Allen	Kane	61.02	5 77	32.40	0.80
,,	Upper Shannon	,,	61.21	5 61	31.44	1.62
Lignite	Cologne	Regnault	63.42	4.98	27.11	—
,,	Patagonia	J. A. Phillips	62.19	5.08	19.44	—
Brown coal	Lower Alps	Regnault	69 05	5.20	22.74	—
,,	Wigan	J. A. Phillips	80 21	6.30	8.54	—
,,	Boghead	Hofman	65.66	8.90	—	—
,,	,,	Anderson	64.02	8.09	5.66	0.55
Cannel coal	Wigan	Richardson	83.75	5.66	8.03	—
Cherry coal	Newcastle	,,	81.20	5.04	8.43	—
Carr's Hartley	,,	Admiralty Inquiry	79.83	5.11	7.26	1.17
Steam Wallsend	,,	,,	83 71	5.30	2.79	1.06
Resolven	South Wales	,,	79.33	4.75	—	1.36
Neath Abbey	,,	,,	89.04	5.05	—	1.07
Graigola	,,	,,	84.87	3.84	7.19	0.41
Aberaman	,,	,,	90.94	4.28	0.94	1.21
Anthracite	—	,,	91 44	3.46	0.79	0.21
,,	Slievardagh, Ireland	,,	80.03	2.30	—	0.23
,,	Vizille	Jacquelin	94.09	1.85	—	—
,,	Swansea	Regnault	91.29	2.33	0.82	0.45

In fact, all three ingredients have disappeared in certain proportions, whilst the carbon, which is always the preponderating element, is least affected.

Fire-damp.—The evolution of inflammable gases at the surface of the earth has long been known to exist near the Caspian Sea, where they accompany the naphtha springs, and on the Schagday, at a height of 7,834 feet. The Holy Fires of Baku are fed by a gaseous mixture containing fire-damp or marsh gas, with 6 per cent. of nitrogen, and from 1 to 5 per cent. of carbonic acid. Marsh gas or methane is also found at Pietramala in Tuscany, at Klein-Saros in Siebenburgen, and in several other localities. It enters also into the composition of the gases which escape from various celebrated springs; as, for example, in the—

Hot spring of Aachen, to the extent of . .	.26—1.82 per cent.
Sulphur spring of Neundorf	.17—1.46 ,,
Mineral spring of Niederlangenau . . .	8.02 ,,
Hercules baths of Orsova	.38—0.88 ,,
Mineral waters of Harrogate	.15—5.84 (cub. inches per gallon

On the hill-side near Kangea, North-western India, Mrs. Colin McKenzie, in her work on "Life in the Mission," &c., says many streams of gas have been ignited, the principal of which are enclosed in a temple by the Hindoos, who look on them with great veneration.

The same gas is frequently met with in salt-mines, where it was first noticed by Guettard and Marcel de Serres.* Bremer also describes an inflammable gas which escaped from a fissure in the bed of marl in the salt-mine at Szlatina in Hungary, and which was employed to light the mine. A similar gas escapes from an old shaft at the salt-mine, Gottesgabe, and it has been noticed at Fredonia and other points near Lake Erie, and more recently

* Mr. T. Hugh Bell mentions ("Jour. Iron and Steel Inst.," vol. i. 1885, pp. 180–182) that gas of the composition, marsh gas 76.9 per cent., ethylene 6.3 per cent., nitrogen 16.8 per cent. by volume, was observed issuing from a bore hole put down by his firm to the salt beds underlying Middlesbrough.

at other places in N. America, especially in the neighbourhood of Pittsburg, Pennsylvania, where it is largely used for industrial purposes (see Natural Gas). It constantly accompanies the salt springs at Marietta in Ohio, and is very common in the salt district of Tseu-lieou-tsing in China, where it is used for the purpose of illumination, and for evaporating the liquor of the salt pans. This gas is also the chief constituent of the gaseous mixture which escapes from the remarkable decrepitating salt of Wieliczka, when it is dissolved in water, first noticed by Dumas, and which, of course, must exist in a very condensed state. Bunsen found it to contain—

Marsh gas	84.60
Carbonic acid	2.58
Oxygen	2.00
Nitrogen	10.35
	99.53

Bischof found the gas which was discharged from a bore-hole sunk for an artesian well in the Princedom of Schaumberg in Germany, to contain, after the separation of the carbonic acid—

Marsh gas	79.10
Olefiant gas	16.11
Nitrogen	4.79
	100.00

Marsh gas is, however, chiefly found in coal-mines, although its existence in brown coal workings has not yet been satisfactorily proved. The explosions which sometimes occur in coal-mines, and which are generally attended with such fatal consequences, are caused by the introduction of a naked flame, employed for illumination, or produced by gunpowder or other explosive substances used in blasting operations in the mine, or a vivid spark of red-hot metal in a mixture of marsh gas with other gases and common air. It would seem, however, that an explosion only follows the introduction of a vivid spark of red-hot metal when olefiant gas is present, as Mr. Clarke mentions having seen the picks of the workmen strike fire in an inflammable mixture without causing an explosion. This circumstance speaks for the correctness of the analyses of the gases from the English mines which are given in the table on p. 61, and which show no olefiant gas.

J. Meyer * has recently instituted a series of experiments to determine the circumstances under which fire-damp may be ignited by sparks produced either by the steel tools used in working in hard rock, or by the friction of pieces of rock against one another. Two to four sharp-edged pieces of steel were pressed, with a pressure of 9 lbs. to 13 lbs., against the periphery of a grindstone of carboniferous sandstone 15.75 inches diameter, and 3.15 inches thick, running at a rate of 250 to 300 revolutions per minute. A continuous stream of sparks of varying intensity was produced, but an explosion was produced only when some of the sparks had an intensity equal to or exceeding the igniting point of the gas. To produce such ignition it was necessary either to force a current of gas against the sparks, or to produce the sparks in the midst of the explosive mixture. Both ordinary illuminating gas and natural gas from a "blower" were used, the latter showing on analysis: Marsh gas, 96.00, carbonic anhydride, 1.10, oxygen, 0.10, other gases, 2.80. No heavy hydrocarbons or free hydrogen could be detected. The illuminating gas was readily ignited after a few seconds, but it was much more difficult to ignite the specimen of fire-damp which was used.

* *Oest. Zeit. für B. u. H.*, vol. xxxiv. pp. 379-82, and 398-401; "Jour. Iron and Steel Inst.," ii. 1886. p 881.

When the grindstone was moistened with water, the danger of ignition was considerably lessened.

When pieces of rock were held against the grindstone with a pressure of about 22 lbs., ignition was more readily obtained with both gases, but it was necessary for the rock to be sandstone. A revolving stone of shale with pieces of shale pressed against it produced no sparks.

With reference to the temperatures necessary for the ignition of different gases, the French Commission on fire-damp give the following:—

	Degrees Centigrade.
Heavy carburetted hydrogen	550
Hydrogen	580
Carbonic oxide	650
Marsh gas	780

Experiments made by the German Commission, however, show that the temperature at which fire-damp ignites is higher than would be indicated by its composition, as they were able to fuse wires of silver and copper in the explosive mixture without igniting it.

The mixture of gases evolved from coal, known in England under the term *Fire-damp*, and in France called *Grisou*, has been repeatedly analysed. The gas from different localities exhibits a general uniformity in composition, consisting principally of marsh gas, with varying quantities of carbonic acid, nitrogen, hydrogen, atmospheric air, and sometimes olefiant gas and sulphuretted hydrogen. The following analyses have been published by different chemists:—

TABLE OF ANALYSES OF FIRE-DAMP.

Colliery or Pit.	Seam or Source of Gas.	Specific Gravity. Observed.	Specific Gravity. Calculated.	Marsh Gas.	Air.	Nitrogen.	Oxygen.	Carbonic Acid.	Hydrogen.	Olefiant Gas.	Authority or Analyst.
Wallsend	Bensham	.6024	.5991	91.00	9.00	—	—	—	—	—	Turner
"	"	—	—	77.50	—	21.10	—	1.30	—	—	Playfair
"	Pipe above ground	—	—	92.80	—	6.90	0.60	0.30	—	—	"
Hebburn	24 feet below Bensham	—	—	91.80	—	6.70	0.90	0.70	—	—	"
"	Ditto (a month after)	—	—	92.70	—	6.40	—	0.90	—	—	"
"	Bensham	—	—	86.50	—	11.90	—	1.60	—	—	"
"	"	.6327	—	—	—	—	0.60	—	—	—	Graham
Jarrow	"	.6381	.6410	81.50	18.50	—	—	—	—	—	Turner
"	"	—	—	83.10	—	14.20	0.40	2.10	—	—	Playfair
"	Five-quarter	—	—	93.40	—	4.90	—	1.70	—	—	"
"	Low Main	—	—	79.70	—	12.30	3.00	—	3.00	—	"
"	Ditto, 11 fathoms lower	.6209	.6079	89.00	11.00	—	—	—	—	—	Turner
Burraton	Yard Coal	.6000	.5903	91.00	9.00	—	—	—	—	—	"
Killingworth	High Main	.6196	.6236	85.00	8.00	7.00	—	—	—	—	"
"	Low Main	.8226	.8325	37.00	46.50	16.50	—	—	—	—	"
"	—	.6326	—	82.50	—	16.50	1.00	—	—	—	Graham
"	—	—	—	66.30	23.35	6.32	—	4.03	—	—	Richardson
Hetton	Main, 100 fathoms	.7800	.7724	50.00	23.00	27.00	—	—	—	—	Turner
"	Hutton, 175 ditto	.7470	.7677	50.00	6.00	44.00	—	—	—	—	"
Pensher	Hutton Waste, 125 ditto	.9660	.9662	7.00	82.00	11.00	—	—	—	—	"
Townley	Three-quarter Seam	—	—	56.17	33.15	4.68	—	6.00	—	—	Richardson
Well-Gate	Five-quarter	—	—	98.20	—	1.30	—	0.50	—	—	Playfair
Gateshead	"	.5802	—	94.20	—	4.50	1.30	—	—	—	Graham
Cwm-Twrch	—	—	—	19.30	—	63.80	15.50	0.80	—	—	Playfair
Wellesweiler	—	—	—	87.43	—	2.22	—	4.30	—	6.05	Bischof
Gerhardt	—	—	—	79.84	—	14.36	—	3.90	—	1.90	"

The presence of oxygen in some of these mixtures has evidently arisen from the difficulty of collecting the gas in a state of purity. The proportion of nitrogen in many of the samples exceeds that existing in atmospheric air, and supports the opinion of Mr. T. J. Taylor and others that fire-damp is not *now* spontaneously generated by or in the coal; this is confirmed by

the extremely variable proportions in which the gas issues locally. Mr. Clarke has also noticed, that as the depth increases, and the pressure of the superincumbent strata becomes greater, the gas is more free from carbonic acid, and more inflammable, while the quantity of water given off diminishes and in some cases disappears, but when present, generally contains a quantity of salt in solution. Bischof indirectly confirms this conclusion, as the result of modern investigations shows that the nitrogen is the product of the decomposition of organic matter under circumstances which do not exist in coal-mines.

The constituents of these gaseous mixtures, when compared with the known composition of wood and coal, enable us to form a very probable conjecture respecting the mode of their formation. It is admitted that coal is the product of the gradual decomposition of wood by a kind of mouldering process under pressure, in the presence of water, and with a very limited supply of air. These agencies have all had a share in the transformation, but we are unable to trace the influence which each may have separately exerted towards the ultimate result, although it is probable that, in the formation of coal from wood, marsh gas and carbonic acid are amongst the products eliminated; carbonic acid, in fact, frequently abounds in the old workings, and being absorbed by water gives rise to the acidulous springs so abundant in the coal measures. The small proportion of nitrogen contained in fire-damp is derived from the nitrogenous substances naturally existing in wood. The occurrence of olefiant and hydrogen gases which are sometimes found must be explained in some other manner, but in reference to the former, it has been remarked that the coking coal from Garesfield, near Newcastle, contains the elements of Cannel coal, *minus* the constituents of olefiant gas.

Henry explains the formation of fire-damp by the action of water on carbon in the following manner:—

$$2C + 2H_2O = CO_2 + CH_4.$$

This, however, is extremely improbable, and is moreover inconsistent with the composition of fire-damp; a high temperature during the formation of coal would probably have given rise to carbonic oxide, a gas which has not been detected in any of the samples analysed; whilst the fact that a similar mixture of gases is observed to rise from the mud of stagnant pools where organic matter is in a state of eremacausis, speaks strongly in favour of the mouldering process.

The large volume of gas which issues from coal in some localities with immense force, in the form of *blowers*, shows that the gas must be retained under enormous pressure. Naphtha, which consists principally of liquid hydrocarbons, is known to exude in considerable quantities from some of the coal formations, a spring of this description being only comparatively recently exhausted at Riddings, in Derbyshire. The natural petroleum springs in America, the Caucasus, France, on the Rhine, and in other places, appear to owe their origin to the same source. Some coal, according to Reichenbach, is impregnated with hydrocarbons, which may be separated from it by distillation with water. A heat greatly below redness is sufficient to separate carbon and hydrogen, not only in the form of gas, but as liquid petroleum, as in Young's processes. Most varieties of coal yield this product, but those possessing the character of Boghead have long been employed for the artificial production of illuminating and lubricating oils.

Mr. Clarke considers that these *blowers* depend on the locality; for instance, in "fiery seams," where *faults* are found running in the direction of the "facings," or the cleavage of the coal-bed—thus forming, as it were, a natural barrier against the exit of the gas—many of the greatest discharges of fire-damp recorded in the north of England have occurred. He

has also found, in driving across the facings or cleavage of the coal, that more gas is liberated, as it were *draining the seam* on each side, in the same way as if the seam were loaded with water.

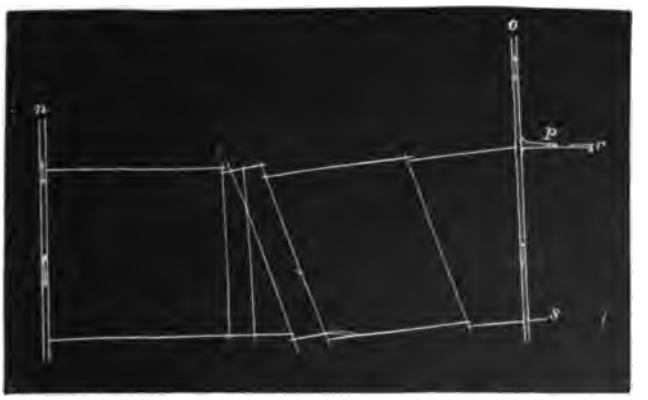
The gases are evolved from all the minute fissures of the coal, generally in a slow and imperceptible manner, but at other times with a distinct hissing sound, as of a confined gas escaping through small apertures from a vessel in which it has been enclosed. This is more frequently noticed when the newly exposed surface of the coal is moistened with water. The gas sometimes exists in such abundance, and of such great tension, more especially in the neighbourhood of faults or dislocations of the strata, that it will dislodge masses of coal, several tons in weight, with great violence, and, mixing with the air, fill the passages of the mine for a considerable distance with an explosive mixture. It is the occurrence of these bags or reservoirs of gas in the workings, which renders mining operations in the deeper coal-beds so dangerous. They are seldom met with in working the upper strata, as the gases find more easy vent through the pores of the superincumbent rocks, and often make their way to the surface through natural channels. Discharges of gas of this kind have been observed in many localities, often at considerable distances from the coal measures. One was described by Thomson as occurring at Bedlay, near Glasgow, which consisted of 87.5 parts of "fire-damp" and 12.5 parts air, and continued to burn for five weeks after it was ignited. At Wallsend Colliery, near Newcastle, as much as 95 cubic feet of gas per minute was evolved from the workings, which, being conveyed in pipes, was used for years in lighting the village, and for a short period at the neighbouring railway station. In all these cases, the gases have a similar origin, but being confined in the deep coal-seams without any natural outlet, they accumulate to such an extent as to acquire very great tension.

The manner in which these dangerous accumulations of gas sometimes occur is well illustrated and explained by the following letter, comprising drawings and descriptions, by Mr. Clarke, formerly viewer of Wallsend Colliery:—

"Walker Colliery, near Newcastle-on-Tyne,
"December 13, 1846.

"The 'high main coal-seam' is here found at the depth of 100 fathoms from the surface, nearly all of which has been wrought out by different shafts, and the 'low main coal-seam' (which is very partially worked) at 160

Fig. 6.



n Jane Pit. *o* Ann Pit. *P* Furnace. *r* High Main Coal Seam.
s Low Main Coal Seam.

fathoms, or 60 fathoms below the previous seam. It is about six feet in height, with two thin bands or layers of 'flue metal' running through it.

"The air descends by the *Jane Pit shaft* into both seams, and the *Ann Pit shaft* is the upcast from both. There is a furnace constantly burning in the high main seam at this shaft, by which the ventilation in that seam is carried on; the heated column of air in the same shaft also causes a sufficient draught to ventilate the low main seam, as shown in Fig. 6.

"I shall now give some particulars of two very considerable discharges or eruptions of gas which have taken place in the low main seam near the Jane Pit shaft.

"The first was encountered on November 13th last, when approaching a 'slip-dyke' or fault, marked *a* in Figs. 7 and 8, from the 'back or slip' of which it displaced a mass of coal about 8 feet long on one side, 4 feet on the other, and nearly 6 feet high, weighing, with the disintegrated or 'danty' coal which had wasted from the slip of the dyke, about 11 tons.

Fig. 7.

Jane Pit shaft.
Upcast to west of 10 feet.
This line in centre of the drift represents the wood brattice to carry the currents into the face of each place.

Fig. 8.

g Jane Pit.

h. Whin Dyke.

i i Coal partially coked.

k Whin Stone.

l Upcast south of 14 feet.

Fig. 9.

t u Low Main Coal Seam.
v Block of coal displaced, together with
w "Danty" Coal.
x Upcast to west of 10 feet.

N.B.—The arrows in all cases show the direction of the currents of air.

"On the displacement of this block, and the discharge of fire-damp which succeeded, being observed by the two men working in the drift, they immediately secured their lamps, one of which had been partially covered with

the fall of coal, but continued to burn, while the other nearest the current of gas had been put out. They then drew down the wick of the remaining lighted lamp, and hastened to apprise the other men in the pit, extinguishing all the lamps as they proceeded, after which they retired to the shaft, according to the printed regulations.

"From observations made at the different places where men were working, the area of drifts or passages fouled at the same moment amounted to 41,681 cubic feet. The point marked *b* was the most distant place north, in the return air channel, where there was any person at work in the mine, although it is extremely probable that the drift would be fouled beyond this spot. After the lapse of from fifteen to twenty minutes, there were no traces of fire-damp.

"The quantity of air circulating in this part of the mine was 10,483 cubic feet per minute, the current passing at the rate of 6.24 feet per second, or 4¼ miles per hour. The area of that portion of the drift in which this current was confined was about 28 feet."

"The second violent discharge of gas took place on December 10th. Before proceeding further, I may notice the precautionary measures that were taken in again approaching this *slip-dyke*. A *bore-hole* was kept constantly in the coal in advance of the face of the *board* (*a*) to prevent the recurrence of such a discharge, and when the last bore-hole had reached the 'slip' of the dyke and the face of the working, within three yards of it, another bore-hole was put in to touch the seam on the rise or west side of the dyke where it penetrated the coal. No discharge of gas issued from it, and the dyke was fearlessly approached, the coal on the east side being taken away to the slip, and a portion hewn out on the rise, or opposite side of the dyke. The position of the seam being thus ascertained, a portion of the roof was removed to carry up the tramways. While this was being done, the 'danty' or disintegrated coal in the slip of the dyke, above the point where the bore-hole has passed through it, was violently forced out with a noise resembling the exhausting of an immense high-pressure steam-engine, which continued some time, and a discharge of gas followed which filled the workings or passages to a distance of 641 yards in length, or an area of about 86,306 cubic feet. At a distance of about 400 yards from the point of discharge, one of the deputies, who had been with some of the workmen conveying materials from the Ann Pit shaft, met the foulness, and on discovering his lamp to be filled with flame, he drew down the wick. The gas continued to burn in the inside of the gauze for about ten minutes, by which time it was red hot, when the current of air having ceased to be explosive, the flame was extinguished. This lamp shows indications of having been exposed to strong heat, the particles of coal-dust attached to the outside being burnt red. At a distance of 641 yards, the foulness was met by four men, who, on discovering their lamps to be on fire, immersed them in a *sump* or pool of water near at hand. It will be seen from the sketch, Fig. 7, that the same dyke had been nearly reached at the spot marked *c* when this eruption took place.

"The velocity of the air, and the time that the gas continued to discharge, render it highly probable that the drift in the direction of the Ann Pit would be foul for a considerable distance beyond the point observed. The quantity of air circulating in the passages at the time was about 16,000 cubic feet, with a velocity in the principal channels of 3.55 miles per hour, and in some of the others considerably quicker. In from twelve to fifteen minutes from its first issue, all traces of the fire-damp had disappeared, excepting to within a yard of the point of discharge, where it mixed with the air, and was carried off. At the blower, the temperature was con-

siderably higher than in the other parts of the mine, which ranged a day or two before at 61°, while at the surface it was 32°.

"It need only be stated that happily no unprotected light had been allowed to be used in the workings of this seam from the commencement.

"These facts prove that in the best state of our present known mode of ventilation, the working of the fiery seam is not safe without the use of protected lights, and assists in explaining how some of the many great explosions in this and other neighbourhoods may have been occasioned, when they could not be attributed to a deficient supply of air.

"On both of these occasions the barometer stood at 30.5."

The pressure of the atmosphere was at one time thought to exert considerable influence on the rapidity with which the gases exude from the fissures of the coal, and accidents were supposed to occur immediately after a sudden fall in the barometer. Mr. Clarke, who made a series of observations, extending over some months, on the evolution of gas in mines connected with the indication of the barometer, arrived at the conclusion, however, that the barometer did not invariably indicate the discharge of fire-damp. In some pits, where candles were generally employed, safety-lamps were lighted when the barometer fell to 29.5 inches, and the candles were extinguished. In others, the men retired when the mercury was observed to be as low as 29 5 inches. When the barometer falls to 29 inches, the gas hisses in some localities in escaping from the fissures of the coal, while, upon a sudden rise to 30 inches, a similar sound is supposed to be occasioned by a return of the air through the pores and crevices.

It is now generally admitted that the variations of atmospheric pressure have little effect on the rate of the escape of fire-damp from the working faces in coal mines, but that where a large reservoir of gas, such as a "goaf" or unventilated space, exists, a large quantity of gas may be liberated from it on the occasion of a fall in the barometer. In this case, however, the gas being much more sensitive to atmospheric change than the mercury, the escape of gas takes place before the barometric indications are sufficiently declared.

It has been suggested * that sudden outbursts of gas are connected with the motions to which the earth's crust is subject, and that the observation of earth-tremors or seismic movements might be made use of in order to foretell such outbursts.

In 1876, Mr. Hall, one of H.M. Inspectors of Mines, made some experiments to show how greatly the escape of gas is increased by the exhaustion of air from a surface of coal.† "An iron tube (4 inches diameter and 4 feet long) was tamped into a bore-hole 18 inches deep, and a pressure gauge was attached to it by a side tube close to the face of the coal. In the tube was an air-tight piston initially at the bottom of the bore-hole. When this piston was withdrawn, there would be a considerably diminished pressure on the 12 or 13 square inches of coal exposed at the end of the hole, and if gas only entered the tube at its normal rate of escape the gauge would indicate the formation of a partial vacuum as soon as the piston passed the junction of the branch-pipe with the main-pipe. In one experiment, in the Bastian seam, a slight diminution of pressure was thus produced, but almost instantly the pressure due to the gas, or to air which had been drawn into the coal and become highly charged with gas, was sufficient to balance the atmospheric pressure. When the piston was forced back into the tube the gas was driven back into the coal and escaped from points, probably small crevices, spread over an area of the face to a distance of 4 to 5 feet from the

* See M. Walton Brown in "Proc. N. of E. Inst. M.E.," vol. xxxiii. pp. 179–183, 165–178.
† See "Final Report Royal Commission on Accidents in Mines," 1886, p. 21.

bore-hole, and when lighted these jets of gas appeared as small flames distributed over the face.

"Similar experiments were tried in the Wigan 9 feet, a very fiery seam, and the Pemberton 4 feet, a seam considered to make very little gas, but in neither case did the gauge show any diminished pressure in the tube, the gas at atmospheric pressure followed up the piston as fast as it could be withdrawn.

"The effect on the escape of gas from coal due to a diminution of the pressure in the air of a mine has lately been put to the test of direct experiment on a large scale in a pit belonging to the Archduke Albert, at Karwin, in Austrian Silesia."

These researches are still in progress, but in 1886 a preliminary report was issued, which showed some remarkable results.

"In addition to a continuous registration of the height of the barometric column in the pit, and frequent chemical analyses of the air passing up the fan-drift, the effect of partially exhausting the whole pit has been tried. The down-cast shaft having been closed as air-tight as possible by a wooden platform covered with clay, the fan was maintained in action at its usual speed—eighty revolutions per minute, giving a difference of level of 60 mm. (2.36 inches) in a water-gauge in the fan-drift, and the quantity of gas leaving the pit was calculated from the velocity of the current in the fan-drift and the composition of the air. In consequence apparently of a leakage from another set of workings having a distinct system of ventilation the height of the barometer in the mine was only reduced 2.5 mm. (about 0.1 inch) below that which it would have had if the down-cast shaft had been open, but the quantity of gas passing out of the mine was increased by about 83 per cent. The existence of old workings, the action of which under diminished pressure is well known, complicated the results obtained by an experiment on an entire mine. A similar experiment was therefore tried in a district (the Karl-Flötz) not connected with any goaf, and which consisted only of an incline 190 metres (208 yards) long, with an accompanying travelling road. In this district, an artificial reduction of pressure to the extent mentioned above caused an increase of 40 per cent. in the output of gas. In other experiments, the shaft from which the leakage occurred was also closed, and a diminution in the height of the barometer of 4 mm. was artificially produced, with the result that in the Karl-Flötz district the output of gas was apparently increased in the ratio of 235 to 100. Numerical determinations in this last experiment were rendered uncertain by the circumstance that, after the exhaustion had continued for seven hours, the current was found not sufficiently strong to move the anemometer, and the fan seemed to have ceased to extract air from the pit, although the difference of level in the water-gauge in the fan-drift remained as before—viz., 60 mm.

"If the indications of the anemometer used in these experiments can be trusted, when running at a low speed, it is very difficult, with the information at present available, to reconcile the large increase of gas observed in these experiments with the fact that no equivalent increase was found when the height of the barometer fell, from natural causes, to the extent which had been artificially produced."

Another cause which probably affects the quantity of gas escaping from the face of coal has been pointed out by Mr. Hall, who regards the possibility of an increased escape of gas from a face of coal on which the pressure is reduced as a matter of importance in considering the effect of a blown-out shot. "The rush of products of explosion from such a shot must cause a lateral diminution of pressure in the air, and under certain circumstances this may affect the gas in the coal. Pro-

bably the conditions most favourable to this action are attained when a shot is fired in the end of a comparatively narrow heading and blows out along the heading. The pressure on the coal forming the sides will then almost certainly be more or less reduced, and an extra amount of gas may be thus suddenly thrown into the air. If a second shot be fired very soon after the first shot, in the end of the same heading, and it also blows out, or emits flame, it is highly probable that the gas just placed in its course will be ignited and produce a blast of a formidable character."

The British Royal Commissioners appointed to report on accidents in mines report that eruptions of fire-damp, which have been termed "sudden outbursts" and "instantaneous discharges," have been much more frequently observed during the last thirty-five years, and that they appear to become more numerous with the augmentation of depth in our own collieries and in those of Belgium. Accounts of these are to be found in the "Transactions of the Midland Institute of Engineers" and other engineering societies, in the Reports of H.M. Inspectors of Mines, and in that of the Royal Commission on Accidents in Mines.

There is great variety in the extent of these outbursts and in the force of the escaping gas. Cases are on record in which a mass of 11 tons of coal has been violently projected into the workings by the escape of the gas, and in which considerably more than a million cubic feet of gas have been given off, whilst it is also recorded that the blower at Garswood Hall Colliery has furnished a supply of gas for over nine years, and that the gas being led to the surface by pipes and there ignited has given sufficient light for the carrying on of the colliery work at night.

The American gas wells (referred to further on under "Natural Gas") are probably due to similar collections of fire-damp, although on a much larger scale.

The maximum tension of the gas confined by water in a limited space of mine, was estimated by one of the leading engineers of the north, Mr. T. J. Taylor, in an experiment made in the Bensham seam, at Percy Main, at $4\frac{1}{6}$ atmospheres; but it required some time to attain this elastic force. A pressure of $4\frac{1}{6}$ atmospheres would fully account for the forcible disruptions which accumulations of gas sometimes produce; but the difficulty still remains of conceiving in what condition the gas can be distributed through the entire coal formation. The pressure at which gas exists in coal, or at which it escapes, has been frequently observed, and of recent years measurements have been made of the pressures developed in cavities bored in different seams of coal in England and South Wales.

The pressures of escaping gas at Pelton Colliery were in 1844 * estimated at 67.5 lbs. per square inch and 912 lbs. per square inch, or sixty-two atmospheres; † and in the measurements carried out by the Royal Commission on Accidents in Mines ‡ pressures of 200 lbs., 461 lbs., 430 lbs., and 318 lbs. per square inch have been observed. Holes were bored in different seams of coal at depths varying from 750 feet to over 2,000 feet below the surface, and the accumulated pressure of gas was observed every hour by gauges. The rate of outflow of the gas was also observed, but it was noticed that the indicated volume of escaping gas bore no relation to the pressure, whilst the pressure appeared to be extremely variable, even in the same seam.

The specific gravities of the various gases entering into the mixture called fire-damp, are as follows:—

* "Trans. N. of E. Inst. M.E.," vol. iii. p. 38. † *Ibid.*, vol. xxx.
‡ "Final Report Roy. Com. on Acc. in Mines," pp. 20, 21.

Air	1.0000
Marsh gas or methane	0.5596
Hydrogen	0.0692
Olefiant gas or ethylene	0.9784
Sulphuretted hydrogen	1.1912
Carbonic acid	1.5290
Nitrogen	0.9713
Oxygen	1.1056

In the mines, the law of diffusion does not in all cases come into practical operation, and the lighter gases are found occupying the upper portion of the galleries and workings, while the carbonic acid may be noticed creeping along the surface as the gases leave the goaf of some pits.

Of these gases, the hydrogen is the most inflammable; when mixed with two or three times its volume of air, it ignites at a temperature just below visible redness, and the flame thus produced will at once ignite the less inflammable gases when mixed in certain proportions with air. It has, however, been rarely detected in fire-damp. Olefiant gas, discovered by Bischof in the mines of Belgium, is also very inflammable, being ignited at a low red heat. It requires 15 volumes of air for complete combustion, and produces twice its own volume of carbonic acid, leaving 12 volumes of nitrogen to mix with the *after-* or *choke-damp*. This gas has not been generally found in the mines of this country. Sulphuretted hydrogen is also very inflammable, and is itself a poisonous gas: it seldom occurs in appreciable quantities in the mines of Great Britain, although the pyrites from which it is derived abounds in some districts of the coal fields. Marsh gas, which constitutes by far the largest ingredient of fire-damp, is not nearly so inflammable as the other combustible gases. It requires about 10 times its volume of air for complete combustion, and produces its own volume of carbonic acid, leaving 8 volumes of nitrogen from the air. Ignition is only produced in this mixture by a white heat, but is instantaneous in contact with flame. The former fact, in connection with the cooling effect of wire gauze, led Davy to the discovery of the lamp which bears his name, and is the parent of the many existing varieties of miner's safety lamp.

These gases, particularly the last, ever issuing from the fissures of the coal, and mixing with the air of the mine, constitute one formidable enemy with which the miner has constantly to contend; and the evidence which has been accumulating for some years in connection with the effect of the presence of coal-dust on explosions in collieries, proves that this enemy is dangerous while existing in the atmosphere of a mine in much smaller proportions than those which with air alone constitute an explosive atmosphere.

With regard to the proportions of an explosive mixture of gases, Coquillon * observed the limits between which a mixture of marsh gas and air can be exploded in a eudiometer by means of the electric spark. He found that with 1 volume of marsh gas and 5 volumes of air, the spark was without effect. With 1 volume of marsh gas and 6 volumes of air, explosion occurred only in a succession of shocks, and this he termed the first limit of possible explosion; the marsh gas being in excess.

With 1 volume of marsh gas and 7, 8, and 9 volumes of air he obtained a sharp explosion, whilst 12, 13, 14, 15 volumes of air for 1 volume of marsh gas gave explosions growing gradually weaker. With 16 volumes of air, the effect was reduced to a series of slight intermittent commotions, and this he termed the second limit of explosion, the air being in excess.

In connection with the investigations of the Coal-Dust Committee of the

* *Compt. Rendus*, 1876, vol. xxxiii. p. 709; "Jour. Chem. Soc.," 1877, i. p. 166.

Chesterfield and Derbyshire Institute of Engineers,* a series of experiments was made with mixtures of coal gas and air in different proportions in order to determine their explosive properties. In these experiments, a cast-iron cannon, 3 feet long, 4 inches diameter, and of a cubic capacity of 267.84 inches, was used as the explosion chamber, and in order to ensure complete diffusion of the gases, one hour was allowed for each cubic foot of gas or air employed. In many cases, however, it was found that a few minutes sufficed to form an explosive mixture. It was ascertained that 1 part of gas to 3 of air, or 1 in 4, inflames but does not explode—it burns quietly. 1 in 5 was distinctly explosive, as were also all mixtures up to and including 1 in 7 or 14.28 per cent. of gas to 85.72 per cent. of air which gave the maximum result in force of explosion. 1 in 7½ had less expansive energy than the preceding mixture, but the difference was not great. All proportions up to 1 in 15 or 6.6 per cent. of gas to 93.3 per cent. of air were explosive, whilst less than 6 per cent. of gas had no explosive properties.

It has been found by the Royal Commissioners on Accidents in Mines,† that the limit fixed by these experiments is too high, and they record that their experiments with lamps in gas mixtures led them to the conclusion that when little more than 4 per cent. of marsh gas is present, flame may be transmitted under circumstances which occur in a mine.

The indications given by the flame of a safety lamp used as a detector of fire-damp were systematically observed by Mr. W. Galloway,‡ but it is difficult to say who was the first observer of the *cap* or *aureole* which is formed on the flame when a certain proportion of fire-damp is present. In his experiments, which were "undertaken to test the accuracy of the means by which the presence of fire-damp is usually ascertained in mines," Mr. Galloway used a Clanny lamp, or lamp with glass surrounding the flame, and the wick was "carefully trimmed and drawn down until the flame presented the appearance of a small blue hemisphere about ⅛ inch high by ¼ inch diameter at the base, having a conical speck of yellow in the middle near the top."

The experiments were made in the cabin of the mine at Llwynypia Colliery, in the Rhondda Valley, and the various phenomena were observed in what would have been total darkness but for the feeble light of the lamp itself. The meteorological observations inside the cabin were, temperature, 57° F., humidity, 79°, barometer, 30.15. The different mixtures used consisted of 1 volume of fire-damp to 14, 15, 16, 18, 20, 25, 30, 40, 50 and 60 volumes of air, and the phenomena observed with the different mixtures are represented in Fig. 10.

When the height of the oil flame was increased to ¼ inch it became luminous, and then the cap was invisible in all the mixtures consisting of 1 volume of gas to 25 volumes and upwards of air.

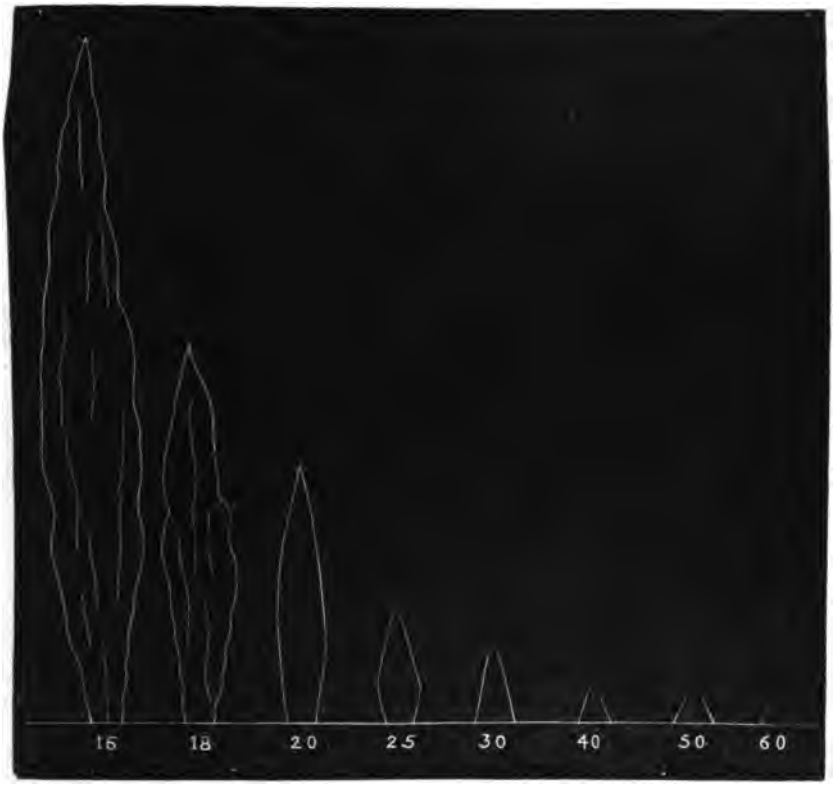
Mr. Galloway concluded that "a mixture of fire-damp and air, in the proportion of 1 volume of the former to 60 (*i.e.*, 1.66 per cent. by volume) or more volumes of the latter, gives no trustworthy indication of the presence of the inflammable gas, when tested in the manner usually, if not always, adopted in mines," but as in his experiments unusual care was taken in reducing the size of the oil flame, we may conclude that ordinary testing for fire-damp in mines does not reveal the presence of any quantity less than 2½ to 3 per cent. Mr. A. L. Steavenson has, however, shown § that the intervention of opal glass renders the cap more distinctly visible.

As, however, Galloway has also shown that "a mixture of fire-damp and air in the proportion of 1 volume of the former to 112 of the latter (or

* "Transactions," vol. x. pp. 36–38. † "Final Report." 1886, p. 19.
‡ "Proc. Roy. Soc.," vol. xxiv. § "Trans. N. of Eng. Inst. Engin.," vol. xxvi. pp. 133–137.

.892 per cent. by volume) becomes inflammable at ordinary pressure and temperature when charged with fine dry coal dust, such as that which is to be found on the roadways in dry coal mines," it is evident that a more sensitive indicator of fire-damp than a Davy or Clanny lamp is a necessity for many mines, if not for all.

FIG. 10.



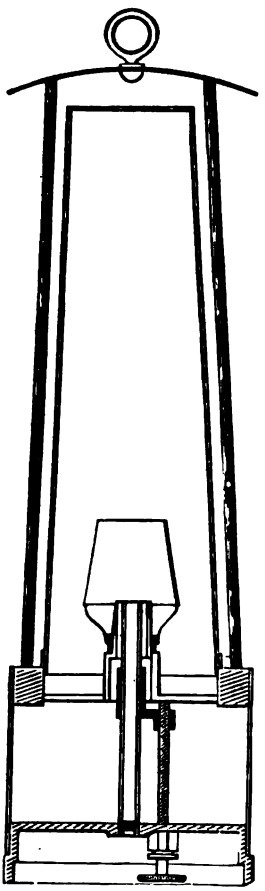
1 Fire-damp to 14 air—slightly explosive.
1 ,, 15 ,, inflammable.
1 ,, 16 ,, gave a voluminous, waving, spindle-shaped pale blue cap, 3⅜ inches high.
1 ,, 18 ,, a similar cap 2 inches high, which burned rather more steadily.
1 ,, 20 ,, a cap of 1 5/16 inch high, cap perfectly steady and more distinct than any of the others.
1 ,, 25 ,, a conical cap ½ inch to ⅝ inch high.
1 ,, 30 ,, a conical cap ⅜ inch high.
1 ,, 40 ,, a conical cap 3/16 to ¼ inch high.
1 ,, 50 ,, an exceedingly faint cap ⅛ inch high, the top having the appearance of having been broken off.
1 ,, 60 ,, it was hardly possible to distinguish anything above the small oil flame.

The experiments of Kreischer and Winkler have the effect of throwing some doubt on the accuracy of Galloway's numerical results, but they also show that the height of the cap varies considerably, for the same mixture of air and marsh gas, with the form of the lamp and with the nature of the illuminant used. They employed five different safety lamps,

two burning benzene, two burning rape oil and one burning a mixture of rape oil and petroleum.

The British Royal Commissioners say of these experiments that "they show that, if the air contains 1 per cent. of gas the reduced flame exhibits only the faintest traces of a cap when the illuminant is benzene or a mixture of rape oil and petroleum, while with rape oil alone even these traces disappear. When 2 per cent. of gas is present in the air, the cap may be distinctly seen on the flame of a benzene lamp, almost as distinctly on the flame produced by mixed rape oil and petroleum, but less distinctly on the flame of rape oil."

Fig. 11.



The safety lamp which is ordinarily used in Britain in searching for fire-damp is proved to be not only inferior to other forms of safety lamps as an indicator of gas, but also unable to give any indication of an atmospheric condition which, if combined with the presence of coal-dust, is one of considerable danger.

This fact, as well as the possible introduction of electric miner's lamps, which cannot give any indication of gas, has given increased importance to other methods which have been devised for detecting fire-damp in smaller quantities than have usually been searched for.

Of these the lamp of Herr Pieler is regarded with some favour in Germany. It is shown in the illustration, Fig. 11, which is (with Figs. 12–16) copied by permission of the Council from the "Transactions of the Mining Institute of Scotland" (vol. viii. part 3). It is a lamp of the Davy pattern, but constructed to burn alcohol with an argand burner, the tube supplying air to the inner surface of the flame passing vertically through the vessel containing the spirit and being protected by discs of gauze. A small conical chimney about an inch high surrounds the flame, which is regulated by a screw, so that in pure air no flame appears above the chimney. All the cap that is seen above the cone is therefore due to gas.

This is said to be a very sensitive gas detector, as small a quantity as ¼ per cent. showing a cap 1¼ inch high, while 1 per cent. gives a sharply defined cap of 3 inches long.

In order to protect this lamp in the currents of well-ventilated mines, and to prevent it communicating flame to the outside of the gauze, it requires, as the British Commission pointed out, to be enclosed in a case.

An excellent description of the various methods which have been proposed is contained in the Final Report* of the Royal Commission on Accidents in Mines, and it is unnecessary to enumerate them. The most

* Refer also to "Trans. Manchester Geol. Soc.," vol. xvii.; "Mining Inst. Scot.," vols. i. ii. and viii.; "N. of Eng. Inst. M.E.," vols. xv. xx:x.; "Chesterfield and Midland Inst. Eng.," vol. xiv.; "S. Wales Inst. of Eng."; *Annales des Mines*, 2nd ser. tome xix. pp. 186–211; *Archives des Sciences Physiques et Naturelles*, Geneva, 3rd ser. vol. v. (1881); *Bull. de la Soc. de l'Indus. Min.*, 2nd ser. vol. vi.; "Jour. Iron and Steel Inst."

notable of them are founded either on chemical or on physical reactions—those making use of chemical reactions operating by causing the combustion of a small quantity of fire-damp in a closed vessel and measuring the resulting contraction of volume.

The reaction is as follows: $CH_4 + 2O_2 = 2H_2O + CO_2$

in volumes $\quad 2 \quad 4 \quad 4 \quad 2$

If the water formed is wholly condensed, the contraction is equal to double the volume of the fire-damp consumed; where the carbonic acid is also absorbed by potash to treble its volume. Fig. 12 shows diagramatically the principal elements of such instruments. "The receiver is fitted with a rubber cork through which passes, air-tight, a glass tube of small diameter and two conductors or electrodes, connected at the top by a spiral of platinum. When we connect the conductors to the accumulator, the current

FIG. 12

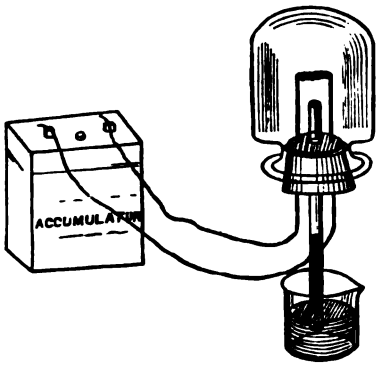
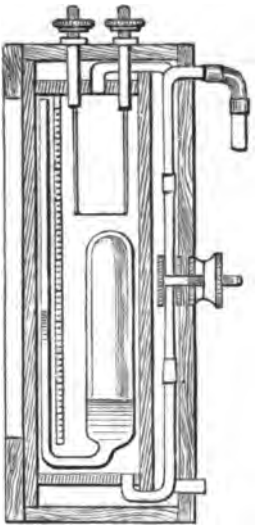


FIG. 13.



passing is sufficient to raise the platinum coil to a white heat. This increases the temperature of the air in the receiver, and would force some of it out, but there is a rubber cork in the foot of the glass tube to prevent this. If we wait till the temperature falls and take out the cork, it will be seen that the water does not rise in the tube. If we now take off the receiver and introduce into it the slightest quantity of coal gas—not too much, or we will have an explosion—then pass the current for a second or two, so as to raise the coil to incandescence, allow the receiver to cool, and take out the rubber cork from the foot of the tube, we shall find that the coloured water rises a considerable distance up the stem."*

The instruments of Coquillon and of Maurice are founded upon this action, that of Maurice being shown in section in Fig. 13. The reservoir is $1\frac{3}{4}$ inch diameter and 7 inches high, and the diminution of pressure due to the contraction after combustion is measured by the expansion of air contained in the bulb within the receiver.

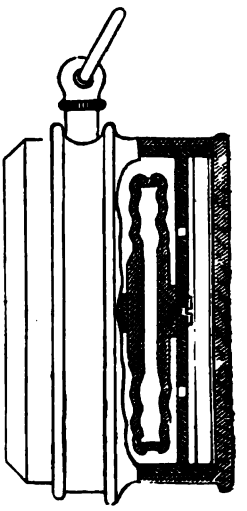
Graham's law of the diffusion of gases, according to which it has been found that "gases diffuse or intermingle with one another at velocities inversely proportional to the square roots of their densities," has been made use

* Mr. J. Gemmell in "Trans. Min. Inst. of Scot.," vol. viii.

of in Ansell's indicator, and in a more recent one by Emmott and Ackroyd. Fig. 14 explains the principle on which they are founded. One end of the tube rests in a vessel containing coloured water, and the other end is closed by a stopper of stucco or some other porous substance. If the tube be filled with coal gas, and the stopper inserted, the coal gas will diffuse through the stucco faster than air enters the tube, and consequently there will be a diminution of pressure in the tube which may be registered or otherwise made use of. In Ansell's indicator (Fig. 15), this diminution of pressure is recorded by means of an index of the kind used in aneroid barometers.

Fig. 14.

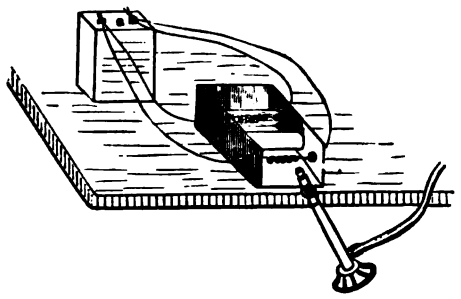
Fig. 15.



In Emmott and Ackroyd's* indicator, two incandescent electric lamps are used—one having clear glass and the other a red-coloured bulb—and the circuit is so arranged that in an ordinary atmosphere the colourless lamp alone shines, whilst in fire-damp this one goes out and the red one is illuminated. This action is produced by the movement of a mercury contact occupying the lower portion of a curved tube, one end of which is open and the other connected with a porous pot of unglazed porcelain, the motion of the mercury being due to the increased pressure in the porous pot occasioned by diffusion.

One of the most important of these indicators is that of Liveing, which utilizes the increased brilliancy of the light given off by a heated platinum wire in contact with fire-damp. This brilliancy is due to combustion of the fire-damp taking place at the surface of the wire and imparting heat to it, and it is compared with the light emitted from a platinum wire heated in pure air. Fig. 16 roughly illustrates the action of this instrument. In a box are fitted two spirals of platinum, one being sealed in a glass tube containing pure air and the other being exposed to the air of the mine (in the illustration to a source of coal gas). A movable screen between them, such as is used in photometric observations, enables the difference of light to be measured by a scale showing the position of the screen.

Fig. 16.



This instrument has been combined with a portable electric miner's lamp by Mr. J. W. Swan,† who has also adapted an indicator on Maurice's plan to his lamp.

The effect of the presence of carbon dioxide on the phenomena exhibited by fire-damp indicators is not yet clearly understood. M. Castel‡ has investigated the action of Coquillon's "Grisoumètre," and has given formulæ for calculating the amount of contraction with different mixtures of gases and different temperatures in the palladium or platinum wire. Messrs.

* "Trans. Phys. Soc.," vol. viii. pp. 69-71.

† See "Trans. N. of England Inst. M.E.," vol. xxxi. p. 117, xxxv. p. 51, and xxxvi. p. 3, "Trans. Phil. Soc. Glasgow," vol. xvii. p. 151.

‡ *Annales des Mines*, 1881, p. 509.

Mallard and Le Chatelier have also acquired indirectly some information bearing on this point, in the course of their experiments on the temperature of ignition of gaseous mixtures.* They used a closed chamber, heated externally, and introduced various mixtures of gases after the chamber had previously been exhausted. The gases investigated consisted of explosive mixtures of hydrogen and oxygen, carbon monoxide and oxygen, and fire-damp and oxygen; and the ignition temperatures obtained for these mixtures were respectively 555° C. (1031° F.), 655° C. (1211° F.), and 650° C. (1202° F.).

These results were found to be independent both of the presence of an inert gas such as nitrogen, or of the proportions in which the explosive gases were mixed. It was noticed, however, as an exception, that the addition of a large quantity of CO_2 elevated the ignition temperature of a mixture of CO and O from 655° C. to 700° C. (1292° F.).

For mixtures of H and CO with O, combustion ensued immediately on exposure to the temperature of ignition. In the case of fire-damp and oxygen, however, it was remarkable that ignition did not occur often till ten seconds after the mixture had been raised to or above the temperature of ignition.† This retardation of ignition may be the result of indirect combination.

Coal Dust.—The credit of being the first to direct attention to the dangerous nature of coal-dust seems to be divided between Robert Bald,‡ "the acknowledged father of mining engineering in Scotland," and J. Buddle,§ the famous North-country viewer, "who was the chief of the Newcastle coal-miners for nearly the first half of this century." Bald pointed out, in "Jameson's Journal" for 1828, the possibility of the ignition, by the flame of fire-damp, of the dust which was to be found in or near the working places of a coal-pit; while Buddle recorded the effects of dust in an explosion which occurred in September 1803, in the Wallsend Colliery.

Some notice of coal-dust accompanying and aggravating an explosion of fire-damp at Felling Collieries‖ in 1812 was also published, but the subject remained in practical obscurity until Faraday and Lyell¶ published, in 1845, their report to the Home Secretary on the explosion which took place at Haswell Collieries in September 1844. This report is notable from its throwing the first clear and unmistakable light on the subject, and demonstrating the method in which action proceeds in a dusty mine when an explosion of fire-damp occurs. The following is quoted by the Royal Commissioners from it:—"In considering the extent of the fire from the moment of the explosion, it is not to be supposed that fire-damp was its only fuel. The coal-dust swept by the rush of wind and flame from the floor, roof, and walls of the works would instantly take fire and burn if there were oxygen enough present in the air to support its combustion; and we found the dust adhering to the faces of the pillars, props, and walls in the direction of, and on the side towards, the explosion, increasing gradually to a certain distance as we neared the place of ignition. This deposit was in some parts half an inch, in others almost an inch, thick; it adhered together in a friable, coked state. When examined with the glass, it presented the fused round form of burnt coal-dust, and when examined chemically and compared with the coal itself, reduced to powder, was found

* *Annales des Mines*, vol. iv. 1883, pp. 274, 379-559.

† See also Berthelot and Vieille, *Compt. Rendus*, xcv. pp. 151-157; "Trans. N. of Eng. Inst. M.E.," vols. xxxi. p. 8, xxxii. pp. 12, 13.

‡ J. Gemmell, in "Trans. Min. Inst. Scot.," vol. viii. p. 99.

§ "Report Roy. Com. on Accid. in Mines," 1886.

‖ "Trans. Chesterfield and Derbyshire Inst. M.E.," vol. x.; "Fossil Fuel, Collieries and the Coal Trade."

¶ "Roy. Com. Report;" "Trans. Ches. and Derb. Inst.," vol. x.; "Phil. Mag.," 1845.

deprived of the greater portion of the bitumen, and in some instances entirely destitute of it. There is every reason to believe that much coal gas was made from this dust in the very air itself of the mine by the flame of the fire-damp which raised it and swept it along, and that much of the carbon of this dust remained unburnt only from want of air. At first we were greatly embarrassed by the circumstance of the large number of deaths from choke-damp, and in the evidence that *that* had been present in very considerable quantities compared with the small proportion of fire-damp, which, in the opinion of those in and about the works just before, must have occasioned the explosion. But on consideration of the character of the goaves as reservoirs for gaseous fuel, *and the effect of dust in the mine*, we are satisfied that these circumstances fully account for the apparent discrepancy."

The fact that the deposit of "dust" accumulated *towards* the explosion above referred to can by no means be wholly explained by the supposition that it was purely *coal* dust. A mixture of marsh gas or fresh fire-damp with gas already exploded, or after-damp, might very well locally occur, and in certain proportions would give rise to a deposition of carbon :—

$$CH_4 + CO_2 = 2C + 2H_2O.$$

It should be observed that a fine sooty deposit—much more resembling synthetic carbon than coal-dust—has in several cases been observed after explosions in mines.

Faraday also lectured at the Royal Institution on this subject in January 1845, and by this means gave greater publicity to it, but nevertheless little attention seems to have been directed to it until recently. The Reports of H.M. Inspectors of Mines mention the effects of coal-dust in connection with the explosions at Ince Hall in 1853, Wynnstay in 1873, Silverdale in 1876, Blantyre in 1877 and 1879, and Penygraig and Lycett in 1880; whilst in the "Transactions" of the Royal Society, the Manchester Geological Society, the North of England, the North Staffordshire and the Chesterfield and Derbyshire Institutes of Engineers the real investigation of the matter belongs to the last ten years.* .

In France, the subject appears, according to the British Royal Commissioners, to have "remained long unknown, for in 1855 M. du Souich, Chief Government Mining Engineer of the St. Etienne Arrondissement, when referring to an explosion which had occurred at Firminy, advanced as new the view that the deposition of crusts of a light coke upon the props was due to dust which had been swept up and transported to a distance by the violent current produced by the explosion, and which, becoming in part inflamed, had extended and prolonged the destructive effects originated by the fire-damp. On the occasion of two explosions in 1861, M. du Souich again dwelt on his views regarding the part played by coal dust in increasing the disastrous effects of fire-damp explosions."

In 1864 M. Verpilleux published† his ideas on the subject, and in 1864–67 he carried out some experiments which substantiated the view that coal-dust plays an important part in coal-mine explosions. Several other French mining engineers carefully investigated the matter, and the records of their work and discussions thereon will be found in the *Annales des Mines* and in the *Bulletin de la Société de l'Industrie Minérale.*‡ In particular, M. Vital carried out experiments in 1875 in connection with "an inquiry into an explosion which had occurred the year before in a part

* See also "Explosions in Coal Mines," by W. N. and J. B. Atkinson (London : Longmans, 1886).

† *Bulletin de la Soc. de l'Indus. Minérale de St. Etienne*, tome ix. p. 468; also *ibid.* vol. for 1875; "Iron," vol. for 1878.

‡ See also Report by M. Haton de la Goupillière on this subject, 1878.

of the Campagnac Colliery where the existence of fire-damp had never been demonstrated. After examining the nature of the dust collected in the mine and instituting some special experiments, though on a very small scale, for the purpose of ascertaining whether, and to what extent, the flame from a small charge of powder was lengthened when projected, like the flame from a blown-out shot, into air containing coal-dust in suspension, M. Vital concluded that very fine coal dust, rich in inflammable constituents, will take fire when raised by an explosion, and that portions are successively decomposed yielding explosive mixtures with air, whereby the fire is carried along, the intensity or violence of the burning being much influenced by the physical characters of the dust."

In Britain, the subject has been investigated with great care and in a thorough manner by means of experiments on a much larger scale than those mentioned, principally by Messrs. W. Galloway* and Hall and Clark† in 1876, Marreco and Morrison‡ in 1878, Sir F. Abel and the Royal Commissioners in 1880–1886, and the Committee of the Chesterfield and Derbyshire Institute of Engineers in 1880–1882. There have been also, in recent years, Commissions appointed in France, Belgium and Prussia for the investigation of this subject and that of fire-damp, and the experiments carried out by the last-named were of a very complete and important character.

The first conclusion arrived at by Vital and Marreco was that flame could be propagated with explosive effects by coal-dust alone in the absence of fire-damp. This accords with the fact that coal-dust has been used as a rapid combustible and also as fuel for furnaces. As to the former, a work by Borgnais published§ in 1818 gives, according to a report to the Institute of France by Berthollet and Carnot, a description of an engine worked by the rapid combustion of fine dust, in a manner somewhat similar to that of the gas engine. The dust used at first was composed of lycopodium, but the engine was found to work equally well with coal-dust mixed, according to need, with a little resin.

In furnaces, coal-dust has been used successfully by Whelpley and Storer in America, and Crampton, Perret and others in Britain, the fine powder being simply blown into a combustion chamber by air, where it is ignited and burns.

The combustible nature of other fine dusts has been frequently proved, as, for instance, by explosions in flour mills, several of these having occurred in America, and one notable one at Tradeston Mills, in Glasgow, which was investigated and reported upon by Professors Macquorn Rankine and Macadam.

The general impression amongst H.M. Inspectors of Mines, however, as witnessed to by the evidence they gave before the Royal Commission, was that coal-dust might aggravate explosions which were caused initially by fire-damp, but that explosions could not be originated or propagated by coal-dust alone. Even Mr. W. Galloway seems to have inclined to that belief at one time, and Messrs. Mallard and Le Chatelier, in France, announced it as the only rational one. It has, however, been conclusively proved to be short of the truth, and the later experiments of Mr. W. Galloway, Sir F. Abel, and the Prussian Commission have set the matter at rest.

Mr. Hall's experiment, which was the first practical experiment with

* "Proc. Roy. Soc.," 1876–84; "Brit. Assoc. Reports," 1881.
† "Trans. N. of Eng. Inst. M. Engineers," vols. xxv. p. 239, xxvi. p. 101.
‡ *Ibid.* vol. xxviii. pp. 85, 156; "Trans. Chesterfield and Derbyshire Inst. M.E.," vol. v. p. 267, vi. pp. 49, 244, 290, vol. x.
§ "Traité complet de mécanique appliquée aux arts; composition des machines, p. 197.

coal-dust known to have been carried out, did not give conclusive proof, as it was not certain that fire-damp was absent. It was made in a brick-arched mine 45 yards long and 30 feet area driven from the surface. When a 2½-lb. shot stemmed with small stones was fired, the flame extended only to 15 feet; but when coal-dust was scattered on deals (the pavement being wet) over the whole length of the adit, and a similar shot stemmed with small coal was fired, the flame extended along the whole length of the mine and issued from the mouth in a large volume, and with a fierce blast which would have been fatal to any one exposed to it.

The investigations of the British Royal Commission dealt with a great variety of conditions.

"Experiments were made in the first instance with a view of ascertaining the smallest proportion of fire-damp which, when mixed with an air current, would furnish an atmosphere capable of firing at a naked flame of a particular size placed in the experimental gallery. It was next ascertained what quantity of gas below that proportion was needed to impart to the mixture of air with a large quantity of each particular coal-dust experimented with, the property of exploding throughout the gallery. By these experiments, the samples of coal-dust were classed in the order of their sensitiveness to explosion, and it was found that, while those which were very rich in pure coal, and which contained the highest proportion of very fine dust, required the lowest proportion of fire-damp in air to bring them to explode readily when suspended in a dense cloud, the order of sensitiveness of samples containing higher proportions of non-combustible matter did not necessarily harmonize with their comparative richness in pure coal nor with their comparative fineness. This was strikingly illustrated by two samples of dust from Seaham Colliery; one of these, taken from the roads, contained more than half its weight of non-combustible matter, yet ranked third in order of sensitiveness; another, which contained considerably more coal and a somewhat larger proportion of the finer dust, ranked only fifth.

"Another point clearly established, and confirming by more accurate data the observations of earlier experimenters, was that the proportion of fire-damp required in a mine to bring dust readily into operation as an explosive material when thickly suspended in the air, borders on, and is even sometimes below, the smallest amount which can be detected in the atmosphere of a mine by the most practised observer with the use of a Davy lamp. Explosions were produced by dust suspended in air travelling at a velocity of 600 feet per minute when fire-damp was present in proportions of 2 to 2.75 per cent.; in currents of low velocity, the same result was produced with a sensitive dust in the presence of only 1.5 per cent. of fire-damp; ignitions which approached explosions in their nature and extended to considerable distances were, moreover, obtained with this dust in air containing still smaller proportions of gas.

"Mixtures of fire-damp and air bordering on those which would ignite on the approach of flame were found to be instantaneously fired by a lamp if they contained only a few particles of dust in suspension, and in connection with this fact the interesting observation was made that such dust particles need not be inflammable or combustible to produce the result named. Mixtures of air and gas which passed a naked flame without any symptom of ignition, were inflamed when particles of a fine, very light powder, such as calcined magnesia, were suspended in them. The action of certain of the pit dusts which contained comparatively little coal, in determining the ignition of mixtures of air and small proportions of fire-damp, was possibly of the same character as that of the calcined magnesia. The power of favouring the ignition of mixtures of fire-damp and air was not exhibited by some other powders similar in fineness to the latter, but differing in

structure and density from this and one or two other non-combustible dusts which may be called active; even different samples of magnesia differing somewhat in lightness from each other, appeared to possess the activity in different degrees. These facts seem to favour the view that a dust which possesses peculiar physical characteristics exerts a contact or catalytic action on gas mixtures, similar to that known to be possessed by platinum and some other substances under particular conditions. Thus, when finely divided platinum, or even a clean, recently heated surface of the compact metal, is brought into contact with mixtures of hydrogen or of hydrocarbon gas or vapour, with oxygen or air, oxidation of the hydrogen or the hydrocarbon is at once established, and proceeds at a rapidly accelerating rate, as the chemical activity is promoted by the accumulating heat, so that the metal is speedily raised to a temperature sufficiently high to bring the surrounding gas mixture to the exploding point.

"In many of the experiments with calcined magnesia, it was distinctly noticed that a dark space intervened between the gas flame used as the source of heat and the flare produced by the ignition of the gas mixture through the influence of the dust-cloud suspended in it; this would seem to indicate that the dust particles, immediately after passing through the flame, establish some amount of oxidation of the fire-damp, which proceeds with increased rapidity as the dust becomes more highly heated through the chemical action developed, so that, within a short distance from the point where the heating commences, the dust becomes incandescent and the ignition of the gas mixture follows. There appears little doubt that this action of non-combustible dust in promoting the ignition of gas mixtures which, in the absence of dust, are not susceptible of ignition by the volume of flame or highly heated matter projected by a blown-out shot, constitutes one element in the dangers arising from the presence of dust in the air of a mine which contains a small proportion of fire-damp, and in which a large body of flame is accidentally produced, either by a powerful blown-out shot, or by a fire-damp explosion of local character."

The power of coal-dust in air, but *in the complete absence of fire-damp*, to convey or to propagate flame, has been carefully inquired into by several experimenters, who have tried several sources of flame. A naked gas flame and shots from pistols and from small cannon were used in the experiments of Marreco and Morrison and of the Chesterfield Institute. Cannon were also used in the experiments of the British and Prussian Commissions, and, in the former, freely exposed heaps of gun-cotton and of slow and quick-burning gunpowder were also exploded in the dust-laden air. The general result of these experiments is, that with air-currents having a velocity of 200 and 300 feet per minute the volume of flame was decidedly increased when the dust-cloud was passing, but when the velocity of the current carrying the dust-cloud was increased to 1,000 feet per minute the increase of volume of flame was more marked, although usually only a *flare*, and not an explosion, was produced. The tendency of the coal-dust flame seemed to be to travel in the direction of the current and not so much against it as was the case with flame produced when dust was absent. The British Commissioners say that the most decisive of their results were not of a nature to warrant the conclusion that flame could be carried along to very great distances by coal-dust in the *complete* absence of fire-damp.

Investigation of the effect of blown-out shots in igniting dust, and of the distance to which any burning effect from a blown-out charge of gunpowder would extend in a mine working in the absence of coal-dust, showed that "cannon when fired into air currents of 100 to 200 feet velocity containing 2½ per cent. of fire-damp, and into a current of 300 feet velocity

containing $3\frac{3}{4}$ per cent. of fire-damp, produced no effect. When discharged into a current containing only $1\frac{3}{4}$ per cent. of gas at a velocity of 100 feet per minute, with coal-dust thickly suspended in it, the portion of the gallery in front of the flash was filled with flame; and with 2 to $2\frac{1}{4}$ per cent. of fire-damp the gas and coal-dust mixture fired with explosive effect."

It was proved also that while the flame from charges of $1\frac{1}{2}$ lb. to 2 lbs. of gunpowder, tamped and untamped, extended to from 20 to 35 feet when dust was absent, in the presence of dust the flame extended to from 37 to 83 feet, according to the velocity of the current and the dryness of the air.

In a countermine gallery 81 feet long, open at both ends, and intersected at right angles by another gallery at a distance of 70 feet from the cannon or shot-hole, charges of 3 lbs. of powder untamped were fired, and coal-dust was blown into the air about 50 feet in the rear of the gun, a current of 70 feet per minute passing from the main into the left branch of the cross gallery. The following results were obtained:—

	Length of Flame in Feet.		
	Main Gallery.	Left Gallery.	Right Gallery.
With slight quantity of dust	50	0	0
„ greater „ „	70	6	0
„ still greater quantity of dust . .	81	12	0
„ „ „ „	81	18	3

The Prussian Commission,* while confirming in several respects the results obtained by other investigators, and especially corroborating the conclusions of the British experimenters as to the influence of coal-dust on non-explosive mixtures of fire-damp and air, have added the following results:—

EXPERIMENTS MADE TO ASCERTAIN THE ADDITIONAL LENGTH GIVEN BY COAL DUST TAMPING TO THE FLAME FROM A BLOWN-OUT SHOT.

Powder Charge. Ounces.	Length of Flame.	
	With Clay Tamping.	With Tamping of Coal-dust of Medium Inflammability.
7·4	9 ft. 10 ins. to 13 ft.	29 ft. 6 ins. to 52 ft. 6 ins.
18.	13 ft.	62 ft.

Experiments† made on the power of blown-out shots to raise and inflame dust, 1 lb. of dust per running foot was laid on the floor of the gallery for 33 feet from the shots. Charge 7.4 oz. of powder fired from cannon near floor

	Length of Flame.
With very fine dusts	69 to 102 feet
„ fine dusts	43 „ 69 „
„ medium dusts	39 „ 49 „
„ coarse dusts	20 „ 39 „
„ anthracite dust (dust tamping)	26 „ 30 „

With inflammable dusts, clay and coal-dust tamping gave the same results. With less inflammable dusts, however, the flame was considerably extended by coal-dust tamping.

While, with coarse dusts of low inflammability, the flame could not be got to reach beyond 39 feet, however far in advance the dust might be

* See translation of Report, by T. W. Bunning, in "Trans. N. of E. Inst. M.E.," vol. xxxiv.
† J. Gemmell in "Trans. Min. Inst. Scotland," vol. viii. p. 106.

strewn, with two very fine and highly inflammable dusts, the flame continually increased as the strewing was extended, until, with 130 feet of the floor laid with them, the flame was projected 16 feet outside the mouth of the gallery—that is, it had a total length of 183 feet.

Violent explosions resulted with either of these dusts when they were strewed in excess of 66 feet, and columns of flame from 3 to 6 feet in height, followed by dense black smoke, escaped from the vent-holes of the gallery. Mr. W. Galloway in his remarks on these results, in a discussion* on them in this country, said that it should be strongly insisted on that Pluto dust (which was one of the two inflammable dusts referred to in the foregoing) created a true explosion. The Report of the Prussian experiments made by Mr. Hilt of Aachen, stated that the effect of all the experiments with Pluto dust was to show that, however long the gallery might be, supposing the dust to be strewn equally far along it, the flame would pass along its whole length. Mr. W. T. Lewis (one of the British Commissioners) and Mr. Galloway witnessed some of the experiments in Germany, and wishing to see the utmost that dust could do, the experimenters strewed a greater length than usual in the gallery to show them, the distance strewn being from 131 to 164 feet. When the shot was fired, there was a practically instantaneous explosion, such as would be produced by gas. "There was a very loud noise, like the firing of a great cannon, the flame came out of the mouths of the safety valves and flew high into the air, and the after-damp filled the whole space over the pit-heap. A waggon, loaded so as to weigh 14 cwt., was driven 52 feet along the railway, rising at an angle of 4 degrees; it then left the rails and ran a further distance of 6 feet on the ground. The end of the waggon, next the explosion, was broken, the boards being actually staved in. There was a small baulk, about 4 inches square, placed across the rails and bolted to keep the waggon from running into the gallery; this baulk was torn away from the bolts and thrown to a great distance over the pit-heap. The brattice, about 1½ inch thick, which was placed at the end of the branch gallery, was completely torn out and broken up." The German experimenters found that Pluto and Neu-Iserlohn dust were equally capable of causing an explosion, but they concluded from their trials, although somewhat hastily, in Mr. Galloway's opinion, that other dusts were comparatively harmless. Mr. Galloway points out that when a colliery explosion has been started, by whatever means, there is a blast of air produced through the mine which raises the dust—coarse and fine together—in a whirlwind. The flame passing along can ignite the fine dust, and if there is a large proportion of coarse particles in the cloud the flame does not travel so fast as when only fine dust is there, but it passes through and ignites the dust in one case as in the other, only delayed a little by coarse particles.

The Prussian experiments were carried out in an elliptical main gallery 167 feet long, 5 feet 7 inches high, and 3 feet 11 inches wide, closed by brickwork at the firing end, but open at the other. At 93 feet from the closed end, a branch gallery 33 feet long left the main gallery at right angles, and was closed by a door having safety valves in it. Seven cast-iron cannon were built into the brickwork, the centre one being 1.57 inch diameter and 37 inches long, and the others 1.38 inch diameter and 31½ inches long, and all pointed to a spot in the axis of the gallery which was 16 feet 5 inches in front of the face of the brickwork.

At the opening of the gallery, and in line with it, an ordinary mine railway was laid to some distance on an incline of 4 degrees, or about 1 in 14,

* "Trans. N. of E. Inst. M.E.," vol. xxxiv. p. 253.

and on this a truck loaded with iron was placed, its propulsion from the mouth of the gallery furnishing a rough indication of the force developed by the explosion in the gallery.

The following table shows the results of experiments made on the elongation of a flame from a blown-out shot produced by coal-dust stemming when fired into gas mixtures :—

Dust from the König Pit.			Dust from Neu-Iserlohn.		
Percentage of Gas.	Length of Flame. Feet.	Distance Truck blown along Railway. Feet.	Speed of Flame.	Length of Flame. Feet.	Distance Truck blown along Railway. Feet.
0	45.9	2.29		49.2	2.60
1	49.2	2.95	One yard	62.3	3.93
2	52.5	3.28	per second	78.7	4.92
3	65.6	4.10		95.1	7.21
4	82.0	7.60	Like lightning	101.7	8.52
5	114.8	10.80	Explosion	118.1	11.10
6	134.5	45.90		154.2	23 to 32.8 Tub much damaged.

It is also held to have been proved by the German experiments that a fire-damp mixture some distance from a blown-out shot can be fired by the flame transmitted by coal-dust; that a mixture containing 7 per cent. of gas with air in the main gallery, exploded by a blown-out shot, exploded coal-dust in the branch gallery, although there was an intervening space of 56 feet altogether free from gas and coal-dust; and that flame produced by the ignition of coal-dust in the main gallery produced an explosion of coal-dust in the branch gallery, although there was an intervening space of 26 feet clear of coal-dust.

The prevention of accidents and disasters from these causes is a matter of the greatest importance in the working of coal, and the fuel industry must be considerably affected in future by the means adopted to secure safety. These would seem to be limited either to the removal of dust, or its being rendered innocuous in presence of flame, or to the discovery of means for the prevention of blown-out shots in blasting, or to the modification of explosives or methods of using them so that escaping flame or sparks will be prevented, or to methods of working free from the dangers attending the use of explosives.

Gases Occluded in Coal.—In almost all coal, there is a quantity of gas which is held mechanically suspended throughout the mass. It is diffused through the pores of the mineral, and may be collected in larger quantities in crevices or cavities, from which as previously mentioned it frequently escapes during mining operations with some violence, thus showing that it has been retained under considerable pressure. Explosions of "fire-damp" and fires in coal-mines are, in many instances, due to this cause, and even after coal has been mined, the continued escape of this "occluded" gas is a source of danger, and is accompanied by deterioration of the quality of the coal. The disastrous explosions which have occurred in vessels carrying coal cargoes, and in the coal-bunkers of steamers, have been traced to this action, and the presence of the gas, even where there is not a sufficient quantity to cause an explosion, greatly adds to the dangers of spontaneous ignition in such circumstances.

Many examinations of the composition of the occluded gas have been made by E. v. Meyer, and his results are collected in the tables given on pp. 84, 85, which were published by Dr. Percy ("Metallurgy").

These tables reveal the inflammable nature of the gas which is given off from freshly mined coal, and they also throw light on the action of the air on coal which is exposed to it for any length of time.

This action is termed "*weathering*," and consists mainly in the combination of the carbon and hydrogen of the coal with the oxygen of the air, carbonic acid and water being formed, while the proportion of disposable hydrogen is reduced.

When pyrites is present, it is also oxidized, especially in presence of moisture, and moderate elevation of temperature accelerates the action. The oxidation of pyrites when present in considerable quantity causes the disintegration of the coal, sometimes to such an extent as to render it nearly worthless.

It will be understood from this that the calorific power of the coal—that is, its practical value as fuel—is seriously impaired by exposure to air, and this may take place so rapidly that in some places coal is known to lose 50 per cent. of its heating value in six months.

These actions may take place without the generation of any sensible heat; but when coal is collected in heaps or in considerable quantities in the holds or bunkers of vessels, oxidation may proceed so energetically as to cause a considerable elevation of the temperature of a part of the mass. This may also take place in the coal-pits, if any quantity of dust or fine slack is allowed to accumulate there, and the point of ignition is frequently reached, so that, in pits, coal cargoes, and in heaps, many serious fires have been known to break out. These dangers of the spontaneous ignition of coal have caused a large amount of attention to be turned to the investigation of the subject, in order that measures might be devised which would lessen the probability of disaster. It has been ascertained that the absorption of oxygen by fine coal, dust, or gum, without the presence of iron pyrites, may generate sufficient heat to cause self-ignition of the coal or of the gases given off; that, as soon as the temperature rises, oxidation proceeds more rapidly; and that the oxidation of pyrites, especially in presence of moisture, greatly adds to the danger.*

The only method of preventing fires from such causes is to keep the temperature of the mass of coal as low as possible, by means of thorough ventilation by currents of air. Various other methods of treatment have been suggested, but none are feasible. It has been proposed to pack coal by hand in vessels in large lumps, to prevent the presence of small coal, but unless the coal were cut in regular cubes, the irregularities of the lumps and the motion of the cargo caused by movements of the vessel would soon result in the manufacture of small coal and even dust: This plan would, therefore, at best only delay the action, besides being open to other objections on the score of cost of handling and of increasing the quantity of unmarketable small coal at the pits. It has also been proposed to seal up the coal hermetically in the holds of vessels, but that is impossible, as the hold of no ship is air-tight, and, moreover, the quantity of air distributed throughout such a mass as a cargo would be sufficient to start the action of oxidation.

The late T. Rowan, in "Spontaneous Combustion and Explosions occurring in Coal Cargoes," &c. (London: Spon), proposed, in addition to ventilation, that coal for shipment should be subjected to a preliminary heating, in order to expel moisture, and thus prevent pyritic oxidation, whilst carbonaceous oxidation would be carried up to a certain point and then checked. This plan is, however, not likely to be adopted, both on account of its cost, and because such treatment would cause a deterioration of the coal by the very oxidation which would be promoted.

* See a Paper by M. Durand in "Proc. Inst. C.E.," vol. lxxv. pp. 230–239.

	Locality.	No. of Cubic Centimetres of Gas yielded by 100 Grms. Coal at 20° C.	Carbonic Acid.	Oxygen.	Nitrogen.	Marsh Gas.	Hydride of Ethyl.
	ZWICKAU.						
I.	"Schichtenkohle;" 700 metres deep; fresh winning	38.0	2.42	2.51	23.17	71.90	
II.	(*a*) Do.; 690 metres deep; had been exposed during 5 years to the ventilation air current of the pit	18.2	16.70	4.90	55.15	3.17	18.61
	(*b*) Do.; gas collected a week after (*a*) had been collected	—	11.40	3.80	60.98	3.44	18.88
	(*c*) Do.; „ a fortnight after (*b*) „	–	12.10	1.10	65.16	3.19	16.85
	(*d*) Do.; „ 3 or 4 months after (*c*) „ during which time the coal was left in a cool dry place	—	12.91	2.57	57.84	4.06	22.68
	(*e*) A portion of the same coal as (*d*) in nuts was kept heated to 45° C., with free access of air, and then treated as the others to expel the gas, which escaped not more slowly than from the coal not heated	—	10.65	3.20	74.72	—	9.80
	(*f*) Used for gas-making at Leipzig	At 15° C. 34.7	2.71	0.16	29.39	59.61	7.68
	(*g*) Gas evolved by the usual treatment after the coal had been previously heated during 24 hours at a constant temperature of 50° C.		15.60	3.10	73.12	—	2.04
III.	"Zachkohle;" 680 metres deep; fresh winning	25.5	4.02	0.62	50.36	45.00	
IV.	Do.; 656 metres deep; exposed during 1¼ year to the ventilation air current; showed traces of weathering externally	18.6	2.25	0.70	23.89	73.16	
V.	"Lehekohle;" 560 metres deep; fresh winning	52.8	0.60	trace	48.00	51.40	
VI.	(*a*) Do.; 690 metres deep; had been exposed during five years to the ventilation air current; appeared outwardly weathered	13.6	7.62	2.44	50.75	15.88	22.35
	(*b*) Do.; gas collected a week after (*a*) had been collected	—	10.10	2.60	50.53	10.18	23.32
	(*c*) Do.; „ 2 months after (*b*) „	—	11.18	2.82	67.99	—	16.36
	From the "PLANEN'SCHE FORMATION." These coals were rich in disseminated iron pyrites; they were greyish-black without the lustre of true carboniferous coals.						
VII.	"Harter Schiefer;" evolved gas copiously; freshly gotten	Not determined	48.7	1.8	4.95		
VIII.	"Weicher Schiefer;" „ „ „	„	38.2	1.2	60.6		
IX.	"Maschinenschiefer;" „ most „ „	„	54.9	1.2	43.9		
	WESTPHALIA.						
X.	"Zollverein" pit, near Essen; gas coal	22.5	7.50	2.59	89.91		
XI.	"Consolidation" pit, „ „	17.4	2.56	4.11	58.48	24.85	

XII. (*a*)	"Sonnenschein" seam, near Bochum; laminated with occasional iron pyrites; freshly gotten	50.6	4.87	2.66	75.82	16.65
(*b*)	Do.; had been exposed during a year to the ventilation air current of the pit	43.2	11.12	2.88	78.60	7.40
XIII. (*a*)	"Dickebank" seam; very like XII. (*a*); freshly gotten	43.3	2.18	2.12	70.51	25.19
(*b*)	Do.; had been exposed for a year to ventilation current	41.2	15.84	3.06	74.53	6.57
XIV. (*a*)	"President" seam; not distinctly schistose; freshly gotten	59.2	5.82	1.99	60.62	31.57
(*b*)	Do.; exposed during a year to ventilation air current	43.6	7.68	2.24	86.77	3.31
XV. (*a*)	"Wilhelm" seam; not distinctly schistose; freshly gotten	54.4	1.30	1.60	66.85	30.25
(*b*)	Do.; exposed for a year to ventilation air current	39.2	4.35	3.35	81.18	11.12
XVI. (*a*)	"Franziska" seam; distinctly schistose; rich in iron pyrites; freshly gotten	54.5	2.02	0.90	86.43	10.65
(*b*)	Do.; exposed during a year to ventilation current	39.6	2.15	3.14	91.28	3.43
XVII. (*a*)	"Leonhard" seam; distinctly schistose and contains iron pyrites; freshly gotten	42.0	3.72	0.39	90.19	5.70
(*b*)	Do.; exposed during a year to ventilation current	3.64	8.49	3.57	87.94	trace

All the specimens from XII. to XVII. inclusive were from "CONSTANTINE THE GREAT" Colliery, near Bochum, and are arranged in the order of their geological age, beginning with the oldest, No. XII.

	Locality.	No. of Cubic Centimetres of Gas yielded by 100 Grms. Coal (?) at 20° C.	Carbonic Acid.	Oxygen.	Nitrogen.	Marsh Gas.	
	NORTHUMBERLAND AND DURHAM.						
I.	From the Low Main Seam, Bewicke Main Colliery	25.2	5.55	2.28	85.65	6.52	Weathered externally
II.	„ Maudlin Seam „ „	30.7	8.54	2.95	61.97	26.54	Very hard, bright, with conchoidal fracture
III.	„ Main Coal Seam, Urpeth Colliery	27.0	20.86	4.83	74.31	—	Bright fracture
IV.	„ 5-quarters Seam, „ about 30 fathoms from surface	24.4	16.51	5.65	77.84	trace	„
V.	„ „ Wingate Grange Colliery, 74 fathoms from surface	91.2	0.34	trace	13.86	85.80	Here and there fibrous in structure
VI.	Low Main Seam, „ „ 108 „ „	238.0	1.15	0.19	14.62	84.04	
VII.	„ Harvey Seam, „ „ 148 „ „	211.2	0.23	0.55	9.61	89.61	Very hard, containing iron pyrites, with bright conchoidal fracture
VIII.	„ Upper or Harvey Seam, Woodhouse Close Colliery, 25 „ „	84.0	5.31	0.63	44.05	50.01	

Mr. J. W. Thomas* has made some examinations of coal which have considerable interest in connection with this subject. Mr. Thomas found that coal, when heated in a vacuum at a temperature of 100° C. (212° F.), gave off an appreciable quantity of gas. When the coal was subjected to a prolonged joint action of the vacuum and heat, not only did the quantity of the products increase, but their quality appeared to vary as the action went on. Late in the action, volatile products came off which condensed to crystalline solids, showing that these hydrocarbons probably did not exist originally in the coal, but were products of the action. Some experiments referred to by the late Prof. Freire-Marreco† showed that, in air, a temperature of about 600° F. was required to produce appreciable decomposition of the coal; but Mr. Thomas's results show that reaction commences, although slowly, at a very much lower temperature than has been supposed.

The following are some of Mr. Thomas's most recent results:—

Sample of Coal.	Gas Evolved by 100 Grms. at 100° C. in a Vacuum.	Carbonic Anhydride, CO_2.	Marsh Gas, CH_4.	Hydride of Ethyl, C_2H_6.	Ethyl, $(C_2H_5)_2$.	Nitrogen.
Wigan cannel 5/3 seam 350 yds. deep	421.3 c.c.	6.44	80.69	4.75	—	8.12
" " 3/2 " 600 "	350.6 "	9.05	77.19	7.80	—	5.96
Scotch (Heywood) cannel, Wilsontown	16.8 "	53.94	—	—	—	46.06
" (Lesmahagow) cannel . .	55 7 "	84.55	—	—	C_2H_6 0.91	14.54
Whitehill cannel shale, Lasswade .	55.7 "	68 75	—	2.67	—	28.58
Whitby jet (finest quality) . . .	30.2 "	10.93	—	—	86.90	2.17

EFFECT OF HEAT ON FUEL.

As combinations of organic origin, the kinds of fuel which have here been described are more or less complex in constitution, and therefore offer but slight resistance to external modifying causes; the different kinds of coal are easily decomposed, and, like other chemical combinations, can only exist within certain limits of temperature, the limit being greater for simple than for complex bodies. These varieties of fuel are not volatile, the chemical equilibrium amongst their elements being destroyed by an increase of temperature long before volatilization can take place; and the decomposition caused by heat is simply an overthrow of the existing arrangement of the elements, while an immediate re-arrangement ensues with the formation of new compounds capable of existing at the higher temperature. The nature of the new products is therefore mainly dependent on the temperature, and these must vary in quantity still more than in quality as the heat is increased or diminished. The admission or exclusion of air (oxygen) during the process will, of course, still further modify the result; in the former case, the products are immediately subjected to the energetic chemical action of oxygen, with which their elements readily combine, and combustion ensues as a secondary process; in the latter, where decomposition by heat is effected without access of air, the coal undergoes dry or destructive distillation, as it is called. The products of this operation can be conveniently collected and studied, and the process demands particular attention, not only because it obtains in every instance of combustion, but also because it is instrumental in producing an important transformation of certain species of fuel. It would, indeed, be a very erroneous idea to suppose that the combustion of wood, coal, or other species of fuel was

* See "Journal of the Chem. Soc.," 1876, ii. 144.
† "Trans. N. of Eng. Inst. M.E.," vol. xxvi pp. 35-37.

simply the result of a direct union of atmospheric oxygen with their elements; on the contrary, the heat produced by the burning of one portion causes the dry distillation of the internal parts nearest to it, before they are brought into contact with the air. When these are at length exposed, they begin to be acted on by the oxygen. In short, it is not the wood which we see burning when a billet is ignited, but the products of its decomposition by the agency of heat. The main points in this process of decomposition by heat in closed vessels (destructive distillation) are the following. From the moment in which the heat destroys the former state of equilibrium of the elements, three circumstances concur in regulating the formation of the new products. These are: first, the temperature; second, the degree of chemical attraction among the elements, or compound groups thereof, increased by their being in the nascent state; and third, their volatility. Hydrogen and oxygen possess the latter property in an eminent degree, whilst carbon is not volatile; there is a tendency, therefore, in the former to separate and pass off in the form of gas; but chemical affinity coming into play causes them to unite, and form new compounds, partly with each other, partly together or separately, with carbon. Among the combinations that are possible, those, of course, will take place in which the elements have the strongest attraction for each other under the circumstances and existing temperature, and, according to Berthelot, they will be those which evolve most heat by their combination. Hydrogen and oxygen combine in the simplest and most stable manner to form water; the excess of hydrogen which is common to all fuel of the coal class, takes up as much carbon as the temperature admits of, forming marsh gas and olefiant gas, while at the same time the united action of the two other elements on the carbon gives rise to a series of ternary compounds. The simultaneous production of all these energetic compounds at a high temperature induces fresh activity, and products of a subsequent action are the final result. In short, the nature of the process admits of the production of an almost innumerable series of compounds. Many of these products are formed in every case of destructive distillation, and some of them require more particular notice. In addition to the gases (*carbonic acid, carbonic oxide, hydrogen, marsh gas,* and *olefines*), a liquid is obtained, the upper stratum of which is an aqueous solution of various substances, amongst which *acetic acid* and ammoniacal salts are the most prominent; whilst the lower stratum, is a mixture of compounds analogous to the resins and ethereal oils, very rich in hydrogen, and is technically called *tar*. *Pyroxylic spirit* or *wood spirit*, a kind of alcoholic compound, is obtained when wood is the substance charred. When any of the varieties of coal are submitted to dry distillation, the products vary; we then obtain from the tar, in addition to the substances discovered by Reichenbach (*paraffin, picamar, creasote, kapnomor, pittacal,* and *naphthalene*), pyrogenous resin, numerous oils, and coal-tar-naphtha, a liquid containing various neutral, basic, and acid compounds.

The less oxygen there is in the fuel, and the more the hydrogen preponderates, as is the case in coal, the more numerous are the products of decomposition which the latter element forms with the carbon. However much the formation of highly carbonaceous products may be facilitated by a suitable temperature, in no case are we able with wood, and still less with turf, or with brown or common coal, to compel the two other elements to combine with and eliminate the whole of the carbon; a certain portion of fixed carbon is always left, its quantity depending on the degree and rate of heating. The original form and structure of wood, brown coal, and turf are retained by the charcoal left by each, so that year-rings and cells may be distinguished in wood-charcoal, which indicate the kind of wood from which it was produced. Coal is affected differently, having a different

elementary composition. Some kinds pass during the process of decomposition into a soft state, or kind of fusion, so that the gaseous products of decomposition are evolved in bubbles, as it were, from a paste; this is the characteristic feature of *coking* coals properly so called, although all coals may leave on treatment a certain amount of fixed carbon. The carbon left by common coal is called *coke;* it is filled with cavities, is more or less dense, and has in general no resemblance whatever to the form of the original coal. The natural moisture, as well as the oxygen present in the fuel which during combustion produces water with the hydrogen, sometimes prevent the attainment of a very high temperature, and therefore it has been the practice, from a very early period, to make use of dry distillation as a means of removing those constituents of the fuel which absorb heat, or as a means of concentrating the heating power, and confining it to a smaller space, besides imparting to the fuel greater strength to resist crushing where confined with a large burden, as in a blast furnace. This is the object of *charring* wood, or of converting it into *charcoal;* and this series of operations has since been applied to peat, brown coal, and particularly to coal itself, the process in the latter case being called *coking*. From the series of natural, a series of artificial fuels is thus obtained, the production of which we proceed to describe. The manufacture of charcoal and coke is in itself a distinct operation, not directly connected with those to be described in another division of the work, in which the dry distillation of certain kinds of fuel is practised for obtaining tar and the gases simultaneously evolved.

WOOD CHARCOAL.

Manufacture of Charcoal.—On examining minutely the process of combustion, when, for instance, the lower end of a chip of wood is ignited, two well-defined periods will be observed. At first, there is a bright flame caused by the ignition of the volatile products of decomposition, which grows less intense by degrees, and is at last extinguished when the gases cease to be evolved, and the process closes with the faint glimmering of the remaining charcoal. If the chip is gradually inserted into a narrow closed glass tube as the flame goes out, the charcoal cools without glimmering, from want of air. It is even possible completely to char the chip, in the manner mentioned above, when access of air is prevented from the beginning by heating the wood in a close vessel. The original mode of preparing charcoal on a large scale was conducted on the former principle, without entirely excluding the latter; but in the more recent methods large close vessels have been resorted to. Whatever plan is adopted, the amount of charcoal is always found to be greatest when time is allowed for the oxygen to combine with the hydrogen of the wood and form water. Experience has, in fact, proved that the slow process of charring is decidedly preferable; this may be seen from Karsten's experiments, by the side of which we place those of Stolze and Winkler.

Winkler enclosed his specimens in crucibles surrounded with saw-dust, and heated them quickly to redness. As a general result, the woods gave nearly a like amount of charcoal; and when the process was too rapid, only half the quantity.

The following are the quantities obtained from 100 parts of air-dried wood:—

Species of Wood employed.	Charcoal.*			
	By a Quick Process of Charring.	By a Slow Process of Charring.		
	Karsten.†		Stolze.†	Winkler †
Young Oak	16.54	25.60	26.1	22.8
Old „	15.91	25.71		
Young Red Beech	14.87	25.87	24.6	17.8
Old „ „	14.15	26.15		
Young White Beech	13.12	25.22	23.8	
Old „ „	13.65	26.45		
Young Alder	14.45	25.65		
Old „	15.30	25.65		
Young Birch	13.05	25.05	24.4	17.6
Poplar	—	—	23.8	17.7
Old Birch	12.20	24.70	24.4	17.6
100 years old Birch, well preserved	12.15	25.10		
Young Deal (*Pinus picea*, D.)	14.25	25.25	23.4	20 6
Old „	14.05	25.00		
Young Fir (*Pinus abies*, D.)	16.22	27.72	21.5	20.1
Old „	15.35	24.75		
Young Pine (*Pinus sylvestris*)	15.52	26.07	23.7	
Old „	13.75	25.95		
Lime	13.30	24.60	22.8	16.2
Ash	—	—	22.1	19.4
Willow	—	—	22.2	15.0
Rye straw	13.40	24.60		
Fern straw	17.00	27.95		
Cane stems	14.65	26.45		

The cause of this remarkable difference in the relative quantities of charcoal obtained is explained by the greater portion of the volatile products of decomposition being evolved at a temperature of 225° C. (437° F.), leaving a substance resembling charcoal, which is not altered at that temperature, but which contains a considerable quantity of oxygen and hydrogen. Rumford obtained the following quantities of residue at 150° C. (302° F.) from 100 parts of the different woods :—

Oak	43.00 per cent.
Elm	43.27 „
Maple	42.23 „
Pine	44.18 „
Lime	43.59 „
Poplar	43.57 „

When this substance, which very much resembles the red charcoal or "charbon roux," is heated to a temperature above 225° C. (437° F.), it continues to evolve carbonaceous products of decomposition until the temperature attains a red heat. The greater part of the charring process can therefore be effected at a temperature probably not very greatly beyond 225° C., but requires a red heat to complete it. As much less carbon is contained in the products which escape below 225° C., the obvious advantage of a slow process is due to that fact.

The modes of charring wood may be classified into *such as require access of air*, and *those in which air is excluded*. To the former belong the meiler and kiln processes, distinguished by the movable or fixed character of the coverings.

* Marc. Bull obtained the same results with air-dried American woods, namely, from 21 to 25 per cent., by igniting angular pieces in crucibles, surrounded with charcoal powder.

† The wood used by Karsten was dried in the air, that by Stolze at 100° C. (212° F.), and that by Winkler in a dry room.

Preparation of Charcoal under a Movable Covering, or Charcoal Burning in Meiler, or Mounds.—The meiler consists of a uniformly arranged stack of wood, partly protected from direct contact with the atmospheric air by a movable covering, composed of turf sods, earth, sand, or charcoal powder, which from its nature enables the burner to regulate the admission of air in any manner that may be required.

The woods that are usually selected for charring are pine, fir, larch, oak, red beech, white beech, ash, elm, alder, and birch; the wood from trees of middle age is preferred, both old and young wood affording a charcoal less dense and hard. The proper age of the different woods will depend on the rapidity of their growth and general longevity, modified, however, by climate and soil. The following data may be taken as a guide:—

	Age of perfect growth.	Age at which it may be felled for charring.
Scotch Fir	140 years	80—100 years
Spruce ,,	150 ,,	70— 80 ,,
Silver ,,	80—100 ,,	60 ,,
Larch	80— 90 ,,	50 ,,
Oak	200—250 ,,	50— 60 ,,
Red Beech / White ,,	120—140 ,,	120 ,,
Elm	80 ,,	20— 30 ,,
Alder	—	18— 20 ,,
Birch	40 ,,	20 ,,

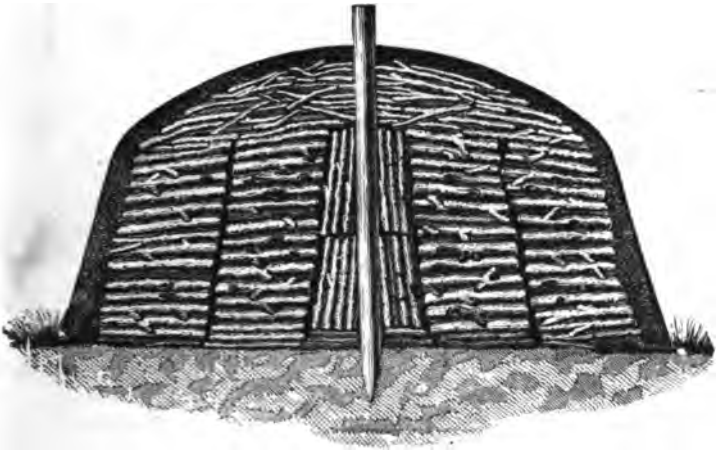
The most appropriate season for felling is the winter, when there is least sap, and when the wood is consequently more quickly dried, and less liable to suffer from dry rot. Wood, half air-dried, is found to yield the densest charcoal; if the wood is too damp, the heap is kindled with difficulty; if too dry, a waste of charcoal results from its greater combustibility; if the wood has suffered from rot, it affords a less dense charcoal. Wood felled in winter, and properly stacked in an airy situation, will be fit for charcoal burning by the end of the ensuing summer. Logs more than 6 inches in diameter must be cleft, and the usual length of the logs is from 3 to 7 feet.

A dry spot is cleared at the proper season of the year, which is during the summer months, sheltered from the wind (by a declivity or a wood); it should be at no great distance from the place where the wood is felled, that the expense of carriage may not be great. The ground must not be damp, or too dry and porous, as in the former case aqueous vapour would rise, and be converted by contact with the red-hot charcoal into carbonic acid and hydrogen; in the latter, currents of air would obtain access to the meiler through the porous soil, and consume a portion of the charcoal. If there is cause to distrust the dryness of the locality, it is well to cover the ground itself, or, after having first made a litter of shingles, planks, or billets, with a layer of charcoal powder several inches in thickness. The construction of the meiler commences at the centre by erecting the stake or quandel as an axis, from which the meiler is afterwards set on fire. This is either a strong post, Fig. 17 (p. 91), around which the logs are arranged concentrically, taking the precaution to leave a free channel at the bottom from the stake to the periphery, that burning coals may be introduced, or three perpendicular logs are connected together with cross-pieces, Fig. 18, so as to leave a kind of open chimney. Whichever plan is adopted, the ignition always begins from the foot of the stake.

Easily combustible pieces, such as partially charred wood from a former process, are placed about the stake, and round these the logs, which must be

as nearly as possible of the same length, and so arranged one above the other in the form of a ring as to leave as small a space between them as possible. The hewn logs are arranged with their sharp edges towards the stake, the bark side being outermost, and all spaces occasioned by crooked blocks must be carefully filled up with small wood, &c. The more slanting the logs are placed, the more loosely they will lie together, and vice versâ; on that account, the external surface of the mound is made as steep as is consistent with its stability and the attachment of its external covering. It is also quite evident that many spaces must be left when the logs are laid horizontally and in a radiating manner round the stake in one or more concentric rings, from the great divergence of outer ends of the logs forming the inner rings. A combination of both forms, as shown in Fig. 17, is therefore practically the best, and the meiler is constructed by placing a number of billets in an upright slanting direction round the stake as a nucleus, and ranging the other logs round this in the form of a ring pressing tightly the nucleus, so that its inclination determines the inclination of the whole heap. In consequence of the laws connected with the management of forests in many countries,

FIG. 17.



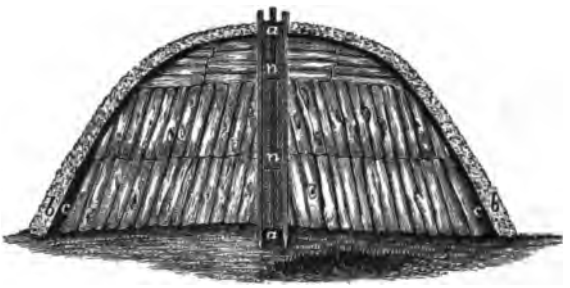
all the logs must be of the same length: the upper horizontal logs approach consequently nearer to each other in proportion to the lessening diameter of the nucleus; thus the external surface becomes surrounded with a series of small steps, which serve a very useful purpose in supporting the covering. In all cases the upper part of the heap is covered with various odd pieces of wood, until it assumes a rounded appearance.

Fig. 17 represents what is called a horizontal meiler. Fig. 18 represents a section of an upright or vertical meiler, the names having reference to the manner in which the logs are arranged round the quandel. In Fig. 18, the quandel is composed of three upright stakes placed at about a foot from each other, and prevented from approaching by cross-pieces of wood. The space between these stakes is filled with brushwood, chips, and other easily combustible matters, to facilitate the ignition of the meiler. Round the quandel, the logs are placed in an upright position, the outer logs being more inclined than those in the centre, in order that the covering may be supported. The upper part is covered with smaller logs in a horizontal position. The logs must be packed as closely as possible together in order to avoid too rapid a circulation of the air; and it is sometimes advisable to

fill up the interstices with charcoal powder from a former operation. The irregularly formed logs which cannot be cleft, roots, and similar pieces are always placed in the neighbourhood of the quandel, where they are subjected to the action of the heat for the longest time. When the meiler is constructed, as in Fig. 18, of two series of logs, the one placed upon the other, special care is requisite to avoid too many spaces being left at the points of support; and to obviate this as much as possible, it is usual to turn the thick ends of the lower series up, while those of the other are placed down. The bark side of the log is always turned away from the quandel.

The size of the mound depends on circumstances, but must not exceed such dimensions as will admit of a good regulation of the heat; some are constructed 10 feet in diameter, and even less, and they may extend to 20, 40, or even 60 feet. It is obvious that the advantage of being less subject to cool is in favour of a large meiler, as its surface is small compared with the space it occupies. The outer surface of a mound 30 feet in diameter, viewed as a hemisphere, will be one-fifth of its contents, while that of a mound 60 feet in diameter will only be one-tenth, so that the surface exposed in the latter will be comparatively only half as great as in the former.

Fig. 18.



The interstices of the meiler having been filled up with small wood, it is next protected from the air, and provided with a *covering*. Moist charcoal powder is best suited for this purpose, as it packs easily and closely together. Sand and earth are not so applicable; any of these matters, however, would fall into the crevices between the logs of wood, if a layer of turf, the earthy side outermost, with leaves, or even in cases of necessity with moss, were not first interposed. This first covering does not extend to the bottom, but is supported at a few inches from the foot by a layer of twigs and brushwood, held by forked uprights in the form of a ring against the heap, which is called its *armour*. This open part at the foot is left for the escape of the aqueous vapour which is evolved in the beginning, and could not be allowed to escape from any aperture in the upper part of the meiler, as too much draught would thereby be caused, with the consequent destruction of much of the wood. The covering, which is from 3 to 5 inches thick at the sides, is made still thicker on the top. When the second covering of charcoal powder or sand has been pressed down, which, however, is sometimes done at a later period, the meiler is then ignited; early in the morning, red-hot coals are brought by means of the channel at the foot of the meiler, or, on the other plan, from the top, to the base of the stake, and the half-burnt pieces and chips about it are ignited as quickly as possible. When this is done, and the opening again closed up, the first period begins—namely, that in which moisture is expelled from the wood—and which is called the *sweating*.

Fig. 19 represents a meiler with its complete covering ready for igniting.

a The top of the stake or quandel.

b The mouth of the channel for introducing fire, which is afterwards closed.

c The lower, and *d* the upper armour.

The most careful watching is necessary, at this period of the process, to prevent the heap being destroyed by explosion and too rapid an evolution of vapour. The duration of the sweating process is easily ascertained by the nature of the smoke, which passes off in the form of a yellowish-grey cloud, while part of the vapours condense in the covering, making it quite moist. As soon as the nature of the smoke changes, becoming grey and lighter, the open part below the armour is covered, and the second period of the process, or the *charring*, commences. The state of the meiler now needs repairs of an important kind; the wood of the stake having been gradually consumed, cavities are left which cause a sinking in and falling together, the covering becomes damaged, and apertures are produced through which air would be admitted. By quickly removing the covering, the top or *cap* of the meiler is left bare for a moment, and the wood in the neighbourhood of the stake is broken up, and beaten down with a long pole, the empty

Fig. 19.

space filled up with fresh logs, and the covering immediately replaced and pressed down. The combustion of the smaller portion of the wood now causes the dry distillation of the remainder, and the charring, properly so called, commences. The meiler is now left to itself for several days, care being taken that openings are made at the foot, to allow the vapours of tar to pass out, and to supply the necessary amount of air, which, however, is partly effected by the porosity of the covering. The circumference of the heap now visibly diminishes, and attention must be paid to see whether this diminution is greater in some places than in others, or whether it presents a general uniformity. If the former is the case, a change of direction must be given to the process by increasing the thickness of the covering in those parts, or by making holes exactly opposite to them, which produce a draught in a different direction. The labour of the charcoal burner would now be at an end, if certain parts of the heap did not require additional care. It is impossible to keep up the fire immediately below the covering, the wood in those parts being too much cooled, and the condensed vapours which collect there impede the progress of the combustion. It therefore becomes necessary before the process is completed (at a time when the wood in the interior is completely charred) to conduct the combustion to the very outside of the heap, by the access of more air.

For this purpose, a second series of holes are quickly made in the upper part of the breast of the meiler, parallel with those in the foot, but at greater distances from each other. It is not necessary to make these holes higher up, as the draught naturally ascends, and produces sufficient heat in the upper parts. After a short time, the thick black smoke which at first escapes from these upper holes assumes the form of a thin blue cloud; the openings are then immediately closed, and fresh ones made about 2 feet lower down, when the same appearances occur a second time. A very large heap requires a third series of holes, close to the foot of the meiler. When fire partially issues forth instead of smoke, simultaneously all round, the process is known to be successful. Wherever flames break out, they are immediately extinguished by moist charcoal powder, and in those places where they do not quickly appear, fresh holes are made to facilitate their production, until at length the whole heap is under cover, and the process complete. The general appearance of the meiler gives some clue as to the nature of the result; although in every case a great contraction has taken place, with careful management this is exceedingly uniform, whilst an inclined position, bulging, and the like, prove the contrary. If the whole heap were broken up before it had cooled, the charcoal would be ignited and destroyed, and to wait until it had completely cooled would involve a great loss of time; the logs of charcoal are, therefore, drawn out separately. The burner lays bare an aperture of tolerable size at the foot of the mound, draws out by means of a hook as much charcoal as time will permit before the air acts too strongly through the opening, and then immediately closes it again; this is repeated round the entire heap, and the red-hot charcoal which is drawn out is extinguished by imbedding it in sand, charcoal powder, or by water; the operation is best performed at night, when the slightest spark is visible. The time required for charring varies with the size of the meiler; small meilers will require from six to fourteen days; but four or five weeks are necessary when the diameter is more than 40 feet.

Charring in Heaps.—Another method of burning charcoal, differing from the preceding in the mode of arrangement and management, but not in principle, is practised in some countries, as at Wienerwald; it is called carbonization in heaps or piles (*Haufenverkohlung*). Round, uncleft logs, of very variable diameter, are usually charred in the heaps, the different sizes enabling the workmen to pack them closely together. It is also desirable to remove the bark from the logs, by which means the fire is more uniformly and easily spread through the entire heap. The removal of the bark should take place immediately after the wood is felled, as it then dries in a very much shorter time. It has been observed by Af·Uhr, that pine-wood felled in June, and placed in a shed to dry, lost the following amounts of moisture, according as it was entire or deprived of bark:—

	From June to				
	July.	August.	September.	October.	
Whole logs . . .	0.41	0.84	0.92	0.98	Percentage of original weight.
Logs deprived of bark .	34.53	38.77	39.34	39.62	

The wood deprived of bark was thus fully air-dried in three months, whilst the whole wood had only lost about 1 per cent. of its weight. The wood is arranged in the form of a narrow, long-shaped wedge, Fig. 20, the breadth of which is entirely occupied by the blocks, while the length is generally from 20 to 30 feet. The thick end, which is likewise the last as regards the course of the process, is from 7 to 9 feet in height, the front thin end being only 2 feet above the level of the ground. Independently of

the lesser height of the heap in front, the gentle slope of the selected spot gives it an inclination in that direction, so that there is a gradual rise towards the back. The choice of position and the mode of covering are the same in this as in the meiler process. The erection is commenced by driving posts all round the measured quadrangle, which in breadth and length must exceed that of the future pile; these posts must be higher towards the back, and correspond in every respect with the height of the pile. Having arranged the unhewn logs, 8 feet in length, crossways upon a floor consisting of long poles placed lengthways, and thus formed the pile, a space 6 inches wide is left between the posts and the sides of the logs, for the reception of the covering, which could not otherwise be attached to the perpendicular sides.

Boards, shingles, or other flat pieces of wood are placed in the inside against the posts, and wet charcoal powder is stamped between them and the logs until the whole side is covered. The thicker end is often constructed in the form of a flat arch, which sufficiently supports the covering without boards. When all the interstices have been filled up, the roof-shaped surface is supplied with a triple covering of twigs, leaves, and lastly of charcoal powder. On the two long sides, a number of holes are previously made in the planks (not in the covering), and a larger one of the same kind in the front for the introduction of small wood for ignition, which is accomplished by thrusting red-hot coals between the poles and the pile. When the fire has kindled,

FIG. 20.

which may be seen by the smoke, the hole is immediately closed; about 15 inches from the ground, other holes, 3 or 4 inches in diameter, are made in the front. The portion of the pile between these now begins to draw, whilst the adjoining higher, thicker part is in the sweating stage. The chief points to be attended to in this process of charring, are the gradual dissemination of the heat and the protection of the charcoal from access of air. If blue smoke escapes from the openings, the process is known to be drawing to a close, the open spaces are closed and fresh ones made at a greater height from the ground, and so on throughout the whole pile. In order to draw the fire down to the bottom, which is more difficult on account of the cooling and humidity, a few spaces are made immediately above the ground in that part which is already nearly charred. When the charring process is advanced about as far forward as the pile is broad, the first portions of charcoal are drawn out. It is sometimes thought preferable to split the logs, and place them longitudinally in a direction parallel with the sides of the pile; by this arrangement, the carbonization is more easily diffused, and fewer openings are required. A well-grounded preference is given to charcoal prepared in this manner; the charcoal, being removed from the heat as soon as it is properly charred, is generally of a superior quality. When this method is properly carried out, the fire should not progress more than 1½ foot daily, so that a heap of 24 feet in length will require about sixteen days for completion, and a heap of 60 feet in length about six weeks.

General Remarks on Heaps and Mounds.—The process of charring wood, which has been known for two thousand years,* belongs undoubtedly to that numerous class of inventions, of which the correct practical discernment of former times has left little to modern theory to supply beyond the rational explanation. Simple and ingenious as the process is, it has not been modified by any essential improvement. It is impossible to imagine a spot where wood is felled, or to which it is brought by flooding, or by wooden sledges, which does not offer the simple requisites for the erection of a meiler; and this circumstance is of importance, as the cost of carriage on wood very far exceeds that on charcoal. It has also already been remarked, that wood diminishes in bulk during charring, as much as from 20 to 25 per cent., so that a heap comprising 3600 cubic feet, becomes 2250 cubic feet when charred, leaving an empty space of 750 cubic feet, from which the air must be excluded or it would destroy and waste a portion of the wood. This vacant space is not, however, produced in the meiler, because the flexible covering, yielding as the wood shrinks, prevents the possibility of such an occurrence. No arrangement could so surely, effectually, and easily regulate the access of air, upon which the main point in the operation depends, as the movable covering. Each thrust of the pole is like opening a stop-cock, each shovelful of earth like closing another, and lastly, the fire can be brought to act consecutively upon every part of the mass of wood, however extensive it may be. The object of the charcoal burner is to char by dry distillation the greater portion of the wood at the expense of the smaller, whilst the latter, in being consumed, affords the requisite heat. A certain portion of the contents of the heap must be considered as the necessary fuel with which the burner effects his purpose. While the admitted air partially consumes one log, the adjoining one is exposed to the heat which it evolves, undergoes dry distillation, and is itself afterwards, for a short time, exposed to the action of atmospheric oxygen. The ability of the workman is shown in excluding the air from the wood at the precise moment when the neighbouring parts are undergoing spontaneous decomposition. This part of the operation is very much facilitated by forcing the vapours, contrary to their natural course, to take a downward instead of an upward direction; the process is thus retarded while the workman is enabled clearly to discern what changes are taking place, and at the same time leisure is afforded him for taking the necessary precautions. It may also be remarked, that the fire, beginning in the middle of the heap, gradually proceeds to the circumference, and thus the centre of the heap, which is the first to be completely charred, is protected from the destructive influence of oxygen by an enclosure of burning wood impermeable to air.

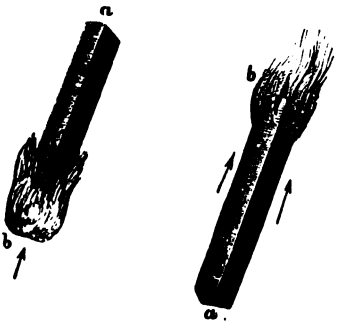
In every process of charring in which one portion of the substance is charred at the expense of another, the current of air by which the combustion is supported must proceed as far as possible from the unburnt portion to that which is undergoing combustion.

If a small piece of wood is ignited, and the burning end held downward, as is shown in Fig. 21, so that the current of air proceeds from the burning to the unburnt extremity, the wood will be speedily reduced to ashes; if, on the contrary, the ignited end be held uppermost, so that the current of air is established from the unburnt to the burning extremity, the portions already half burnt are surrounded by the products of the combustion of the parts below them, and these exclude the free access of air and prevent their reduction to ashes. But when the greatest possible amount of charcoal is desired, although the products of the combustion of the one portion are less prejudicial than atmospheric air as an envelope for the red-hot charcoal,

* It is described by Theophr. Erosius, who lived 300 years B.C., and by Pliny.

yet even these should be as much as possible excluded from contact with it. The products of the combustion of wood consist chiefly of carbonic acid, carbonic oxide, hydrogen, carburetted hydrogen, aqueous vapour, and the vapours which subsequently condense to form tar. If a current of carbonic acid is carried through red-hot charcoal, each molecule of it, CO_2, becomes converted into two molecules of carbonic oxide, $2CO$, by taking up carbon from the charcoal. Carbonic oxide, carburetted hydrogen, and hydrogen are not altered by passing through red-hot charcoal, nor do they affect the charcoal, unless by making it more dense; aqueous vapour is, however, decomposed, producing with carbon, at first carbonic acid, which then becomes carbonic oxide, and hydrogen. These products, therefore, if allowed to pass through the ready formed charcoal must diminish its quantity.

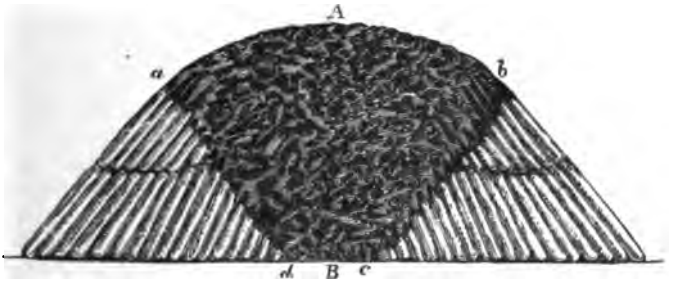
FIG. 21.



Both in the meiler process and in the heaps, the direction of the draught is necessarily from the burning towards the unburnt wood; at the time of ignition, and also for some time after, during the sweating, a portion of the wood is consequently reduced to ashes, hence the necessity for refilling the space thus left vacant. During the true charring period, very little air has access to the meiler, and the two conditions most essential to a good yield of charcoal are closely observed. The air that finds access is in the direction from the unburnt to the burning portion, and if some holes are made in the upper part of the meiler, the products of combustion escape through these without traversing the red-hot charcoal; these conditions obtain until the process is completed, and it is only during the first period of the operation that some better arrangement is desirable. This has been partially effected in stationary meilers, on the plan proposed by Brune.

At the commencement of the true charring process, according to Ebelmen's

FIG. 22.



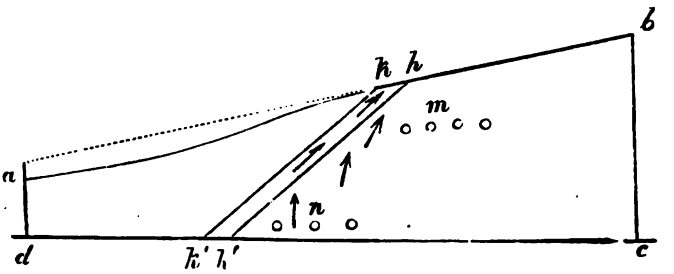
experiments, the interior of the meiler presents the appearance indicated in Fig. 22.

The charred portions surround the quandel in the form of an inverted truncated cone, *a*, *b*, *c*, *d*. If smoke-holes are made at *a* and *b*, the products of combustion which escape through them do not pass directly through the red-hot charcoal, whilst the current of air entering through the covering and at the uncovered foot is in the direction from the unburnt to the burning portions.

In the heaps, it is always the object of the burner to advance the charring

process in the upper part before the lower, so that if *a*, *b*, *c*, *d*, Fig. 23, represents the longitudinal section of a heap some time after ignition, *a k k' d* will represents the charred portion which has sunk together somewhat, *k k' h' h* the zone of wood actually undergoing decomposition, and *h h' c b* the wood which is more or less unchanged. The charred portion is surrounded with the close-fitting covering, the air entering by the holes *n* is drawn towards the inclined zone of decomposing wood, where it supports the combustion, and passes off with the products of decomposition through the loose covering above the zone, and through the draught-holes *m*. The essential conditions, before adverted to, are consequently carefully followed. The air traverses the heap in a direction from the unburnt to the burning portions of the wood, and the volatile products do not pass off through the charred product. There is no great difference, therefore, between the two methods of charring as regards their theoretical efficiency. The heaps, however, offer a comparatively much greater surface for the admission of air through the covering, a disadvantage which is partly compensated by the opportunity they afford of withdrawing portions of the charcoal before the entire heap is charred. Although, on the whole, the meiler may have the advantage of affording a larger percentage of charcoal, the smaller amount of labour required in adapting the logs for the heaps, the greater facility of

FIG. 23.



covering, and the superior quality of the charcoal, which is both denser and in larger pieces, make the latter process preferable under many circumstances.

Ebelmen has endeavoured to ascertain what portion of the combustible ingredients in the meiler process are consumed in converting the remainder into charcoal. Is the wood charred at the expense of the volatile products of the dry distillation, or at the expense of a portion of the charcoal? The conclusion at which he arrived, from the comparative analysis of the gases from the meiler and gases from a retort in which wood was charred, was in favour of the view that the whole of the heat necessary to char the wood in a meiler was derived from the charcoal; that, in fact, the volatile products of decomposition were primarily the same in both methods of charring, but the gases from the meiler process were mixed with the products arising from the combustion of additional charcoal at the expense of the oxygen of atmospheric air. Scheerer, however, has shown* that it is nearly impossible to estimate accurately the amount of charcoal thus consumed, and that the volatile products of decomposition in the meiler process must be consumed to a considerable extent. He calculates that at least $\frac{1}{4}$ of the tar is burned. This, however, seems doubtful; as in most such processes, tars are apt to simply recede from the heat.

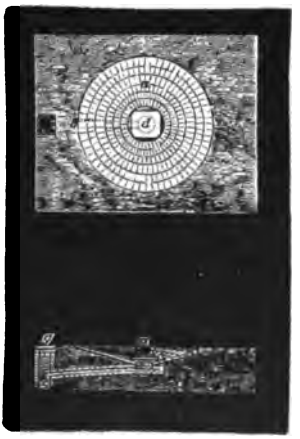
At Hiflau, in Styria, and at Reinhardswalde, the process of charring in meilers has been modified in some respects, with a view to increase the

* "Lehrbuch der Metallurgie."

quantity of charcoal. The meiler is erected on a porous foundation constructed of stones and sand, the foot is closed during the first part of the operation, and the ignition is effected at the top instead of the bottom of the stake or quandel, the air being forced by this arrangement to traverse the meiler in a perpendicular downward direction from the top to the bottom of the meiler; the necessary heat is communicated almost entirely by the dry wood, which is filled in at intervals from the top. In these processes, less air is admitted to diminish the yield, but the charcoal is more subject to the action of the gases produced during the charring, the effect of which has been described above, and which in some measure counterbalances the advantage derived from the admission of less air.

The great drawback to the meiler process is the total loss of all available secondary products, such as tar and pyroligneous acid; and many improvements on the process have been proposed with a view to secure these. The advantageous disposal of these products is greatly dependent on the wants of the surrounding district, and is often exceedingly difficult; various methods for collecting them have been tried, however, although not always with success. The means adopted for collecting the secondary products in the meiler process have generally proved unsatisfactory, in consequence of the inferior quality of the charcoal and the smaller yield which is then obtained. Some have proposed to form the covering of slaked lime, in order at all events to preserve the acetic acid as acetate of lime; others, that it should consist of portable hurdles covered with clay, which being supplied with tubes might carry off the vapours to condensing vessels. This, however, would be robbing the covering of its most useful quality, its flexibility. The long heaps or piles are better suited for condensing arrangements, and the best plan is to place a tube in the covering at the thicker end which shall conduct the vapours to a vessel containing water. When it is not necessary to change the spot chosen for the heap and follow the wandering course of the woodman, where the wood, as in mountainous districts, can always be brought to the same spot by sledges or otherwise, a stationary meiler may be constructed, and the base of the heap may be built in the form of a flat funnel, the middle and lowest part of which is connected with a channel leading to a pit at the side, in which tar and pyroligneous acid may be collected.

FIGS. 24 AND 25.



Stationary meilers are sometimes constructed on a nearly horizontal circular bed of brickwork, either inclined from the circumference towards the centre, or from the centre towards the circumference. In the former case, a short perpendicular tubular space is left in the centre, leading to an inclined channel, which ends in a small brick tank or reservoir at the side, in which a portion of the condensable products of combustion collects during the process. The tubular space is loosely covered with a grate or iron plate to prevent the charcoal from falling into it. The reservoirs must be covered during the process, so as to prevent the air from entering through the central aperture, and the products cannot be removed until the charring is completed. A construction of this kind is shown in Figs. 24 and 25.

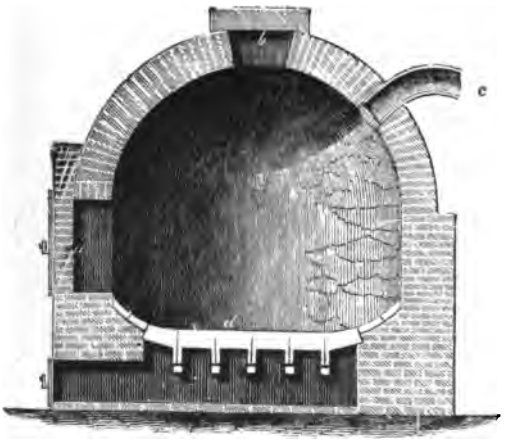
The ignition of the meiler, when stationary, may be advantageously effected by modifying in some measure the construction of the foundation, as proposed by Brune, and alluded to above. Instead of piling the wood

upon the brickwork, an annular wall of brickwork is erected about 1 foot or 1½ from the surface, upon which are placed iron plates supported by cross-bars of iron. Three apertures are left in this wall for the admission of air below it; and into this space brushwood and other combustible matters of little value are placed and ignited, by which means the iron plates become red-hot, and communicate their heat to the wood in the meiler above them. By closing the apertures in the wall the draught can be regulated. It is found unnecessary to heat the entire surface of the iron plates in order to ignite the meiler; a heated surface of 5 feet in diameter, when situated in the centre, being sufficient to ignite a meiler of 30 feet diameter. This method, according to a report by Ebelmen, affords a larger produce of charcoal than when the ignition is effected in the usual manner by a quandel shaft. Although the quantity of air admitted to the meiler during the sweating part of the process is much diminished by this method of ignition, yet a considerable quantity must be admitted to keep up the requisite temperature, and none of the attempts to improve this part of the process have as yet proved satisfactory.

Charring in Kilns.—The attempt to obtain all the products simultaneously, with a greater amount of charcoal, probably first led to the substitution of stationary apparatus, either of brickwork or iron, in place of the covered meilers. Some of these arrangements are calculated, like the heaps, to produce the necessary temperature for charring, by the combustion of a portion of the wood, and the admission of a little air: such as kilns, the sides of which form a fixed covering for the substances to be charred. In others, the portion of the wood destined to produce the heat is entirely separated from that to be charred; the latter being placed inside, the former outside the kiln. The gases and vapours evolved from wood in the process of charring are themselves fuel, and are unavoidably lost in the heaps, so that it becomes an object, when these are evolved in large quantity, to bring the operation as quickly as possible to a close, in order to retain the combustible ingredients in the charcoal.

In the kiln represented at Fig. 26, the air has access through the bars of a grate at *d*. The kiln is filled through the aperture *a*, and afterwards from *b* in the roof; the charcoal is only discharged at *a*. All the openings are bricked up during the operation, the draught being regulated by means of a tightly fitting door to the ash-pit. The air is allowed access until the walls of the furnace have attained a heat sufficient to complete the carbonization, the doors are then completely closed, and earth is thrown against them, when thick smoky vapours of tar make their appearance. The volatile products escape through the pipe *c*, which is connected with a condenser. The process in these kilns is not so easily watched or so much under command as in the meiler, where the movable covering indicates the progress of the operation. A very long time elapses before the charcoal

Fig. 26.



is sufficiently cool to be removed, and the kilns require frequent repairs, which increase the expense of the manufacture. On the other hand, the kilns can be more regularly worked, being independent of the weather.

In Russia, Sweden, and according to Kavanko in China, carbonization is usually effected in pits, the sides of which are made to form the kiln. The pit is generally situated on the side of a hill, and is in the shape of an inverted cone; at the side is a tar vessel, which is connected with the sole of the kiln by an inclined tube. The pit, having been filled with finely cleft wood, is closed at the top with a covering of earth, through holes in which a draught is produced. The kiln proposed by De la Chabeaussière is a carefully constructed pit, which is worked upon the same principle, and, like the preceding, is more adapted for the production of tar than of charcoal. The form being the same, a draught is produced from below by means of a number of channels, which pass down the sides of the kiln, and open laterally above the sole. The whole is covered above with an iron hood, in such a manner as to allow the conducting pipe for the tar to enter a few inches below it. In consequence of excessive cooling, a quantity of wood in these kilns remains only half-charred.

The kilns, in which carbonization is conducted by means of a series of holes made in the wall, are different from the above. They are made to contain from seven to eight stacks (100 cubic feet each) of wood, are quadrangular, that the wood may be more closely packed, and slightly arched at the top. The lowest series of holes is on a level with the sole, the next 18 inches higher, and the remainder at distances of 3 feet from each other. The wood having been introduced, and packed as closely together as possible, a channel is made above the sole, corresponding with and accessible by the doors, by means of which the whole is ignited. A pipe from the upper part of the furnace carries off the vapours. Distinct apertures are left for charging the furnace, and drawing out the charcoal. When the process has begun in the kiln, and a certain temperature has been attained, the holes are closed with clay plugs, one after the other as the process progresses, and when it is nearly finished the whole furnace is covered with clay. The charcoal must not be removed until the furnace is completely cold, or the air, on entering, would consume a large proportion of the red-hot charcoal. It requires two or three weeks to cool.

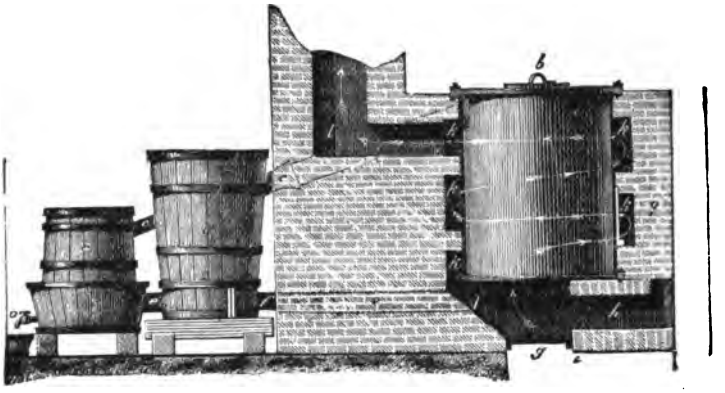
The second kind of kiln, which is heated by fire from without, and which entirely excludes access of air, admits of all the products being completely collected, an advantage which is counterbalanced by the necessity of employing small vessels and small quantities of wood at a time, that the bad conducting power of wood and charcoal may not offer an insurmountable obstacle to the penetration of the heat to the central portion.

In addition to this, the cost of fuel for effecting the dry distillation becomes a serious obstacle, amounting generally to 20 or 25 per cent. of the wood to be charred; and although the gases, after the condensation of the tar, have been economized in some forms of apparatus, and burnt under the retorts as fuel, yet the process has not proved profitable, especially as these gases act very severely on iron retorts.

Coniferous woods have been found to produce the largest amount of tar, on account of the highly hydrogenized resins and the turpentine with which they are impregnated; those parts which contain the most resin are, therefore, chosen. Kilns, or rather retorts of this description, are more applicable to the production of tar, and the volatile products of dry distillation, than of charcoal; they are, indeed, generally called *tar retorts* or *furnaces*, and are often constructed entirely of clay, in the vicinity of the spot where the wood is felled. They consist of two hollow cylinders, one within the other, arched over at the top; the inner one, destined to receive

the resinous logs, extends with the aperture in its dome somewhat beyond the outer one, which, leaving an annular space of a few inches, rises close up to the dome. The space between both is appropriated to the fire, a few holes being left in the outer cylinder for the admission of air. The bottom of the inner cylinder is made in the shape of a funnel, terminating in a tube, leading through the intermediate space and the external cylinder to the tar cistern. When the furnace is charged with wood, the aperture is closed, and fire is made in the annular space as long as tar distils over below. The thick upper fluid layer in the condensing vessels, which at first is yellowish-brown and at last blackish-brown, is the tar—a solution of pyroligneous resin in volatile oils, and acetic acid; if it is separated from the lower watery layer and distilled by itself, a mixture of these latter is obtained, pine-tar oil (Kienöl), and the resins remain as ship's-tar, or *pitch*. According to Stolze, the foliaceous woods produce from 9 to 10, the coniferous woods 13 to 14 per cent. of tar. More recent authorities give as low as 5 per cent. for the former and as high as 18 per cent. for the latter. A very good arrangement for obtaining both charcoal and tar is shown in Fig. 27. The

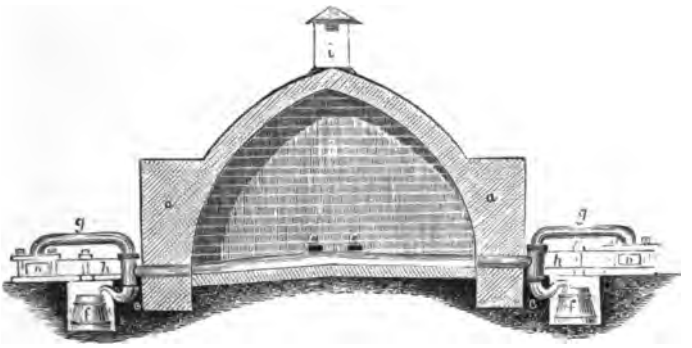
FIG. 27.



space in which the wood is to be charred is an iron box (brickwork requiring too much fuel to heat), which will contain one, or at most, two stacks; it is placed over a grate, in such a manner that the flame shall pass in a spiral manner round its sides and into the chimney; *b* is the door for filling; the tube *c* carries off all the volatile products, first through the cooler *d*, whence the condensed products are conveyed to the receiver by the tube *e*, whilst by another tube *f* the gases pass to the fire-hearth. When the fire produced by the combustion of faggots at *g* has raised the box to a red-heat, the first vapours which appear carry with them combustible gases; as soon as these are produced in abundance, the cock at *v* is opened, and they are admitted to the fire, where they burn, and afford sufficient heat to finish the process without any additional fuel. After about sixteen hours, the fire is extinguished by shutting off the gases, the whole apparatus is allowed to cool, and the charcoal removed. It has already been mentioned, that furnaces, like the one here described, when compared with heaps, can only char small quantities at once; experiments have been made to overcome this difficulty by constructing larger boxes, and supplying them with heating pipes, so that the heat might be applied not only at the surface, but also to the centre. If the heating is conducted in such a manner that the flame contains little or no excess of oxygen, the pipes may then be dispensed with, and a saving of fuel effected by carrying the ignited gases at once into the body of the

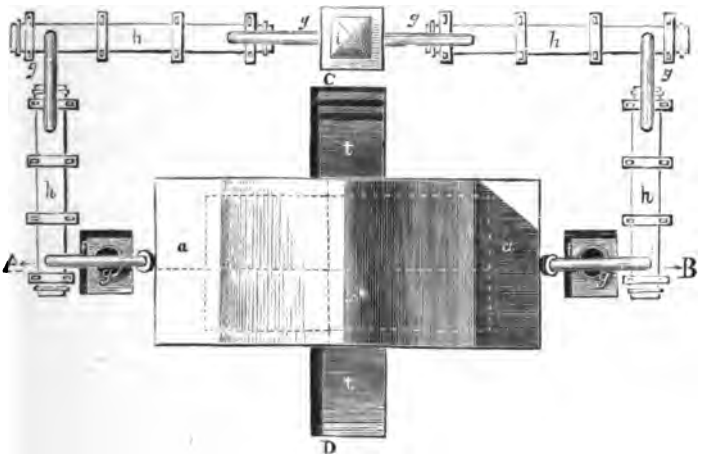
charcoal. The furnaces introduced by Schwartz into Sweden are constructed on this principle; they are large, close, walled spaces, into which on the one side, the flame from the hot gases is introduced from a hearth built for the purpose, and from the other issues the tar-pipe.

Fig. 28.



A longitudinal section of Schwartz's furnace is shown in Fig. 28, corresponding with the line *A B* of Fig. 29. The brickwork chamber *b* is 17 feet high, 27 feet long, and 17 feet deep; the arch being 2 feet thick. The flames from a furnace situated on the outside enter by the apertures *c c*, which are about 15 inches in diameter and 2½ feet apart. Two similar apertures, leading from another furnace, are situated on the opposite side of the kiln. The sole of the furnace is raised in the centre and inclines towards the sides, where two 15-inch pipes, connected with the bent

Fig. 29.



pipes *e e*, are inserted, for carrying off the tar and other products of distillation. The tar which first condenses flows into the vessels *f f*; the more volatile acetic acid, wood-spirit, &c., are conveyed by the pipes *g g* to the condensing boxes *h h*, which are arranged at the back of the kiln and terminate in the chimney *i*, which is necessary to produce a draught through the entire apparatus. In Fig. 29, the arrangement of these condensers is better seen; *t t* are two pits, whence the furnaces are supplied with fuel.

The arrangement of the fire-hearths is seen in Fig. 30 at *c*; they contain no grates, which would afford too much draught, and are bent in the form of a knee, to break the current of air. The apertures *d d* serve for charging the kiln with wood, and are bricked up during the firing. The walls must be perfectly sound and without cracks, nor must any lime, cement, or mortar be employed about the interior of the kiln, where it would be exposed to the vapour of acetic acid. Fig. 31 is a front elevation of the kiln.

Fig. 30.

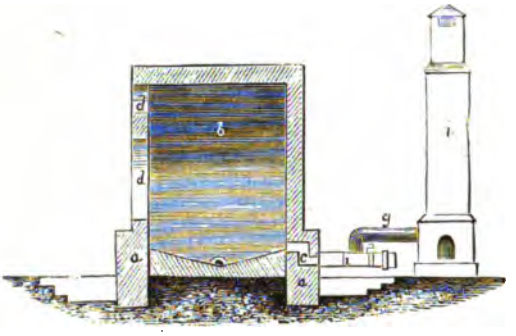


Fig. 31.

In working one of these kilns, the floor is laid with about 2 feet of light faggots, upon which the wood is piled as closely as possible, except in the immediate neighbourhood of the openings for the flame, where a space of a few cubic feet is left. During the whole period of charring, the fire-hearths must be kept filled with fuel, to prevent the ingress of air. When light-blue smoke issues from the chimney, the process is finished, and the fire-hearths are closed up as completely as possible. In the course of a day or two, water is poured over the charcoal, from holes in the roof of the kiln, and this is again repeated after some time; when the metal pipes *e e* appear quite cold, the charcoal may be withdrawn without fear of rekindling. The quantity of fuel consumed is about 20 per cent. of the quantity of wood charred. Some of the charcoal is lost owing to combustion with water during quenching.

As it is quite impossible totally to exclude the air from these furnaces, and under all circumstances some carbonic acid and much aqueous vapour must be produced from the combustion of the fuel, these gases, coming into contact with the red-hot charcoal, will necessarily reduce its quantity, and the produce is consequently not found to exceed that obtained in the ordinary meiler. They have, however, one advantage over the meiler, which will always render them an economic auxiliary to that process, and this consists in the facility which they afford for charring wood of all shapes and sizes, and the pieces, such as roots, branches, and unshapely logs, that are rejected by the charcoal-burner as ill-adapted for the construction of the meiler.

Many of these kilns are employed in Sweden, where much wood charcoal is still used for metallurgical processes, and are found to last for a long time. One furnace will produce about 2700 cubic feet of charcoal per month, throughout the year; the first cost of the kiln amounts to about £35.

In other places, it is found more economical to employ the waste heat from some other operation than that from a separate fire. Thus, the flame from blast furnaces has, it is alleged, been employed with success for the

purpose, several kilns being arranged round the mouth. Supposing these all to be filled with wood, the flame is conducted through a sliding-door into the first, until the heat is sufficient to complete the charring; the door is then closed, and the flame is conducted to the next, and so on. Before the charge in the last is completely charred, the first kiln has in the meantime been refilled.

Heated steam has also been proposed as an agent for producing wood charcoal; but has only been practically employed in the manufacture of red charcoal, for the preparation of the superior kinds of gunpowder.

The Produce.—The yield of charcoal is apparently, at first sight, very variable. The experiments undertaken by Juncker, at Berthier's instigation, at the smelting works in Poulaouen, afford perhaps the most trustworthy results. The following woods, all thirty-two years old, were first weighed and then charred in similar heaps of five stacks each. The weight of the charcoal was ascertained immediately after its preparation, before it had had time to absorb aqueous vapour. Unfortunately, however, the quantity of water in the wood was not previously estimated. The following results were obtained:—

Species of Wood.	Charcoal.	Half-charred Wood.
	per cent.	per cent.
Green Red Beech, cut in May 1832	19.7	0.6
,, ,, ,, ,, without bark	23.0	0.3
Dry ,, and Oak, 2 years old	24.0	0.3
Dry Oak, 2 years old, without bark	25.7	0.34
Green Oak, cut in May 1832	22.4	0.3
,, ,, ,, without bark	21.2	
,, ,, ,, with bark	18.8	1.0
Equal parts of barkless Red Beech and Oak, cut January 1831, and carbonized in August 1831	23.4	0.5
Green Red Beech, with bark, charred immediately	12.9	0.3
Green Oak, immediately charred	13.5	0.4

The first five experiments were made in August, and consequently at a favourable season; the last five in January, when the weather was unfavourable. The mean produce of the whole series is 20 per cent. Beschoren obtained, at Eisleben, in meilers of 20 feet circumference, the following quantities:—

	I.	II.
From Oak-wood (split-logs)	21.3	23.4 per cent.
,, Red Beech ,,	22.7	— ,,
,, Birch ,,	20.9	— ,,
,, Beech ,,	20.6	— ,,
,, Pine ,,	25.0	— ,,

F. Meyer, in five experiments on fir-wood logs, charred in meilers of 30 feet circumference, at Elend in the Hartz, obtained 20.8, 21.2, 23.7, 21.7, and 27.5 per cent. of the wood employed.

At Hiflau in Styria, and at Görsdorf in Saxony, coniferous woods are found to yield 26 per cent. Af Uhr states the produce from five meilers, in Sweden, of 30 feet diameter, and 10 feet high, as 25.2, 20.7, 26.4, 20.0, and 28.0 per cent. Omitting the last two experiments of Berthier, the mean of these twenty-six experiments will give 23 per cent. as the produce from the meiler. The mean produce from kilns is, according to Karsten's experiments, about 26 per cent.; as, however, a quantity of wood is

consumed in heating the kilns, amounting to about $\frac{1}{8}$ of the quantity charred, these twenty-six parts will in fact be the produce of 120 parts of wood, and, therefore, only about 22 per cent. in reality, being not so much as the average quantity produced in meilers. The erection and repair of the furnaces moreover entail an outlay, which very much exceeds that required for attendance on the meiler. None of the methods described produce more than $\frac{2}{3}$ths of the whole amount of carbon contained in dry wood, so that there can be no doubt as to the inefficiency of all the processes. The wood, in the state in which it is employed, contains 20 per cent. of hygroscopic moisture, 40 per cent. of hydrogen and oxygen, and 40 per cent. of carbon. The carbon is consumed during the ordinary process, in various ways; firstly, in evaporating water contained in the wood, and that which is formed by the union of oxygen and hydrogen; secondly, in producing, with portions of the other elements, tar and pyroligneous acid, &c.; thirdly, in evaporating these; fourthly, in producing a red heat throughout the mass of charcoal; and fifthly, in supplying the constant loss of heat: that which remains after a supply has been furnished for these different purposes is the *produce* in charcoal. If the whole of the hydrogen be supposed to unite with oxygen, without taking up any carbon, there will be 40 + 20 = 60 per cent. of water to evaporate; this, as will be shown below, will require $5\frac{1}{2}$ per cent. of charcoal; of the remaining 34.5 per cent., 0.6 will be consumed in bringing the whole to a red heat, and from 1 to 2 per cent. will necessarily be uselessly burnt. Any method by which the remaining 32 per cent. of charcoal could be obtained would be of great value. It appears, from experiments made in America, chiefly by Dr. H. M. Pierce, of Elk Rapids, that there are good prospects of such a saving being effected. By charring in kilns heated entirely by gaseous fuel generated in separate furnaces, he has obtained 30 per cent. increase of yield of charcoal above that of the ordinary method, besides an increased quantity of acetic acid and wood spirit. Several papers in the Journal of the United States Association of Charcoal Ironworkers and in Proc. American Inst. of Mining Engineers may be consulted with advantage on this and kindred subjects.* According to Stolze's experiments, the carbon contained in the tar and acetic acid amounts to 11 per cent. of that contained in the wood. Statements, like those of Kavanko, according to which the Chinese obtain from 30 to 35 per cent. of charcoal from fresh wood, or the entire amount of carbon, are difficult to understand in the absence of information as to their methods of charring.

It is not unusual in many places to calculate the amount of produce by volume, in which case the unoccupied space left between the pieces of wood and of charcoal must be taken into the calculation, and this cannot be done with any degree of certainty. (1) The gross volume of the wood (including the interstitial spaces) is sometimes compared with the gross volume of the charcoal; (2) at other times the actual volume (deducting the interstitial spaces) is compared with the actual volume of the charcoal; and again, (3) the gross volume of the wood may be compared with the actual volume of the charcoal.

The following observations have been recorded on the first mode of comparison:—

	Produce.	Observers.
Fir and Pine logs (Sweden) . . .	50.5—75 per cent.	Af Uhr
Pine logs (Hartz)	50.0—70 ,,	
Split Beech-wood	60.8—61.8 ,,	Pfurt

* See abstracts of these in Journal of the Iron and Steel Institute, vols. 1882–1883–1884.

The second mode of comparison yielded:

	Produce.	Observers.
Pine logs, mean of five meiler experiments (Hartz)	47.6 per cent.	
Split Pine logs (Saxony)	60.0 ,,	Lampadius
,, ,, ,, ...	69.5 ,,	Foy, Gruner, Harlé

Beschoren obtained the following comparative results at Eisleben:—

	By Weight.	Compared according to Method (1).	Compared according to Method (3).
Oak-wood . . .	21.3 per cent.	71.8 per cent.	98.7 per cent.
,, . . .	23.4 ,,	74.3 ,,	102.0 ,,
Red Beech-wood .	22.7 ,,	73.0 ,,	100.4 ,,
Birch ,, .	20.9 ,,	68.5 ,,	94.2 ,,
White Beech ,, .	20.6 ,,	57.2 ,,	78.6 ,,
Scotch Fir ,, .	25.0 ,,	63.6 ,,	87.2 ,,

Any estimation of the produce in charcoal by volume is subject to the great objection that the most porous pieces, and such as are full of cracks, count equally with the denser and more compact.

Properties of Wood Charcoal.—Wood charcoal is a substance which varies very considerably in composition and properties not only with the source or kind of wood from whence it is derived, but also with the degree of temperature to which the wood has been submitted in the process of manufacture. As prepared on a manufacturing scale by the processes already described, it never consists of pure carbon, but always retains some volatile ingredients, which can be driven out by a strong and continued red heat; moreover, there is the ash contained in the original wood, to which hygroscopic water must be added, if the charcoal has been some time prepared.

All the varieties of charcoal may be conveniently classed under the heads of *hard* and *soft* charcoal, the former being derived from the hard close-grained woods, such as oak, beech, &c., whilst the soft foliaceous and coniferous woods afford *soft* charcoal. Another and more important distinction arises from the temperature employed in the manufacture, as on this the amount of volatile ingredients depends. Highly charred wood is called from its colour *black* charcoal, whilst that prepared at a lower temperature goes by the name of *red* charcoal, or *charbon roux*, the preparation of which will be described presently.

Good black charcoal is very dark in colour, of a bright lustre, and somewhat conchoidal fracture; when allowed to fall upon a hard surface it produces a sharp sonorous noise; it withstands a gradual pressure to a considerable extent, but is easily broken in pieces by a sudden blow; it soils the fingers but little, and the dust is easily removed. Charcoal swims on the surface of water. Ignited, it should burn without flame or smoke. Bad charcoal soils the fingers, is not sonorous, and burns with smoke and flame. A remarkable property of charcoal is its power of absorbing gases in its pores, more particularly those which are easily liquefied, as gaseous ammonia, hydrochloric acid, sulphuretted hydrogen, and carbonic acid. Of the first, it will absorb 90 times its volume, and 35 times its volume of the last; of oxygen it condenses 9.25, of nitrogen 7.5, and of hydrogen 1.75 times its volume. It also condenses aqueous and offensive vapours from the atmosphere, on which account it is sometimes employed to remove the unpleasant odours from clothes, and it also retards putrefaction when brought into contact with matters undergoing decay. The amount of water absorbed by different varieties of charcoal appears to depend on their degrees of porosity

and the length of time during which they are exposed. According to Nau's experiments, the freshly prepared black charcoal from different woods will absorb during the first twenty-four hours after preparation quantities of water varying from 0.8 to 16.3 per cent. of its weight, as is shown in the following table :—

	Amount of Water absorbed in Twenty-four Hours.
White Beech charcoal	0.80 per cent.
Ash ,,	4.06 ,,
Oak ,,	4.28 ,,
Birch ,,	4.40 ,,
Larch ,,	4.50 ,,
Maple ,,	4.80 ,,
Pine ,,	5.14 ,,
Red Beech ,,	5.30 ,,
Horse-chestnut ,,	6.06 ,,
Elm ,,	6.60 ,,
Alder ,,	7.93 ,,
Scotch Fir ,,	8.20 ,,
Willow ,,	8.20 ,,
Italian Poplar ,,	8.50 ,,
Fir ,,	8.90 ,,
Black Poplar ,,	16.30 ,,

The effect of longer exposure to the atmosphere on the quantity of water absorbed by charcoal is shown by the following results obtained by Werlisch :—

100 parts of Birch-wood charcoal weighed:	
On the 24th of June	100
,, 30th ,, ,,	104.35
,, 7th ,, July	105.63
,, 16th ,, ,,	106.57
,, 29th ,, ,,	107.62
,, 20th ,, August	108.16
,, 17th ,, September	108.44

The charcoal employed for these experiments was taken some time after it had been burned, and not quite fresh from the meiler, so that in all probability it contained about 4 per cent. of moisture, or the quantity which birch-wood charcoal is shown in the first table to absorb in twenty-four hours, and the total quantity taken up in eighty-five days would be not less than 10 or 12 per cent. In moist weather, this would be absorbed in less time, and probably increased in quantity. From these results, it appears difficult to form an estimate of the actual quantity of water absorbed by charcoal, but about 12 per cent. may be safely assumed as an average. Berzelius estimates it at from 10 to 20 per cent.

The volumes of various gases absorbed in twenty-four hours by one volume of charcoal as determined by de Saussure are as follows :—

Ammonia	90 volumes
Hydrochloric Acid	85 ,,
Sulphurous Acid	65 ,,
Sulphuretted Hydrogen	55 ,,
Nitrous Oxide	40 ,,
Carbonic Acid	35 ,,
Olefiant Gas	35 ,,
Carbonic Oxide	9.42 ,,
Oxygen	9.25 ,,
Nitrogen	7.50 ,,
Marsh Gas	5.00 ,,
Hydrogen	1.75 ,,

The higher the temperature at which the charcoal has been produced, the less moisture and gases it absorbs from the atmosphere, because it is then more dense. For more recent figures, reference may be made to Hunter's inves-

tigations ("Journ. Chem. Soc.," xviii. 285; xx. 160; xxi. 186; xxiii. 73; and xxiv. 76). It has been found that charcoal, after prolonged contact with atmospheric air, contains from half to twice its volume of a gas which may be regarded as $CO_2 + 4N_2$.

Ash.—The amount of ash contained in charcoal varies with the kind of wood employed in its manufacture. From 100 parts of wood (containing 20 per cent. of moisture), an average amount of twenty parts of charcoal is obtained, so that the quantity of ash contained in it must be five times as great as that in the wood. The average quantity of ash in wood varies between $\frac{1}{3}$ and 1 per cent., and the charcoal should consequently contain about 3 per cent. Winkler in general found less, as shown in the following table:—

	Amount of Ash.		Amount of Ash.
Lime-wood charcoal	3.55 per cent.	Pine-wood charcoal	1.38 per cent.
Maple ,, ,,	2.27 ,,	Poplar ,, ,,	1.30 ,,
Ash ,, ,,	2.27 ,,	Beech ,, ,,	1.25 ,,
Elm ,, ,,	2.17 ,,	Scotch Fir-wood charcoal	1.11 ,,
Willow ,, ,,	1.50 ,,	Birch ,, ,,	0.80 ,,
Fir ,, ,,	1.44 ,,	Oak ,, ,,	0.75 ,,

These twelve results only yield a mean of 1.65 per cent. Other kinds have been found, however, containing as much as 5, and even nearly 10, per cent. of ash. In most respects, the composition of charcoal ash is identical with that of the wood from which it is made; it is, however, liable to contain less oxygen, sulphur, and nitrogen, and to be more caustic when freshly prepared.

The specific gravity of the different kinds varies considerably, and is of importance in their application as fuel. The very accurate experiments of Hassenfratz yielded the following results:—

	Specific Gravity.		Specific Gravity.
Birch-wood charcoal	0.203	Red Fir-wood charcoal	0.176
Ash ,, ,,	0.200	Maple ,, ,,	0.164
Wild Service-wood charcoal	0.196	Oak ,, ,,	0.155
Red Beech ,, ,,	0.187	Pear ,, ,,	0.152
White Beech ,, ,,	0.183	Alder ,, ,,	0.134
Elm ,, ,,	0.180	Lime ,, ,,	0.106

The following statements are the mean of numerous observations made on a large scale:—

1 cubic foot of	Beech-wood	charcoal	(split logs),	interstices included,	weighed	8	to 9	lbs.
1 ,,	,,	,,	(brushwood)	,, ,,	,,	7	,, 7·5	,,
1 ,,	Oak	,,	(split wood)	,, ,,	,,	7	,, 8	,,
1 ,,	,,	,,	(brushwood)	,, ,,	,,	6	,, 6.5	,,
1 ,,	soft	,,	of different kinds	,, ,,	,,	4·5	,, 5·5	,,
1 ,,	Pine	,,	,,	,, ,,	,,	5·5	,, 7	,,

It is a remarkable circumstance that a preference is given by consumers to charcoal that has been stored for some time and has absorbed moisture; more actual heat is said to be derived from it in that state than when freshly prepared. Probably the absorbed moisture and occluded carbonic acid facilitate combustion, and create an impression that there is a greater total heat.

When charcoal is stored in large heaps, it becomes crushed, and much is reduced to powder, in which state it is useless as fuel, the air not having sufficient access to enable it to burn. As much as from 12 to 16 per cent. is often sacrificed when the charcoal has to be carried to any distance. A process for working up this refuse dust will be noticed below.

Black charcoal is a very bad conductor of heat, and requires a high temperature for ignition; once ignited and amply supplied with air, it

burns easily. The highest degree of combustibility is developed in the charcoal which has been reduced to powder in revolving drums with metallic balls, as employed in the powder factories. So great is it, indeed, that sometimes spontaneous combustion occurs, which may perhaps be accounted for by the heat generated by the condensation of air in the porous charcoal raising the temperature sufficiently high to enable the particles of carbon to exert their affinity for oxygen.

The average composition of black charcoal may be stated as follows:—

	Fresh.		Old.
Carbon	97	...	85
Ash	3	...	3
Hygroscopic Water	0	...	12
	100	...	100

RED CHARCOAL—CHARBON ROUX (ROTHKOHLE).

It has already been stated, that the object of charring wood is to increase the amount of combustible matter per volume. Thus, a cubic foot of beech-wood, weighing 20 lbs., after abstracting the hydrogen and oxygen present, contains nearly 9 lbs. of combustible matter; a cubic foot of beech-wood charcoal, on the contrary, contains no other ingredient, and weighs 12 lbs. We have, therefore, increased its combustible matter $\frac{1}{3}$ per cubic foot, and yet it is by no means essential that the carbonization be perfect, as is the case in charcoal from the meiler process, in order to obtain this result. Berthier pointed out this fact some years ago, and Sauvage has now proved it by a series of interesting experiments: the latter charred five equal parts of air-dried wood, in the same furnace, one after the other, and interrupted the process each time at a different interval, in order to examine the products of the various degrees of carbonization, as to their loss of weight and bulk, and the amount of combustible matter they contained. He found that:

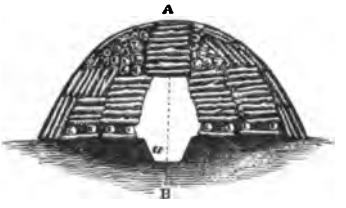
100 lbs. Wood charred for	3 hours	4 hours	5 hours	5½ hours	6½ hours	Mound Charcoal
weighed . . .	65.4 lbs.	53.0 lbs.	47.0 lbs.	41.5 lbs.	39.1 lbs.	17.2 lbs.
and 100 cub. ft. measured	86 cub.ft.	76 cub.ft.	58 cub.ft.	55 cub.ft.	52 cub.ft.	33 cub.ft.

Lastly, they contained of combustible matter:

1 cub. ft. wood	908	parts by	weight
1 ,, ,, charred during 3 hours . . .	883	,,	,,
1 ,, ,, ,, ,, 4 ,, . . .	904	,,	,,
1 ,, ,, ,, ,, 5 ,, . . .	1133	,,	,,
1 ,, ,, ,, ,, 5½ ,, . . .	1091	,,	,,
1 ,, ,, ,, ,, 6½ ,, . . .	1136	,,	,,
1 ,, meiler charcoal	1069	,,	,,

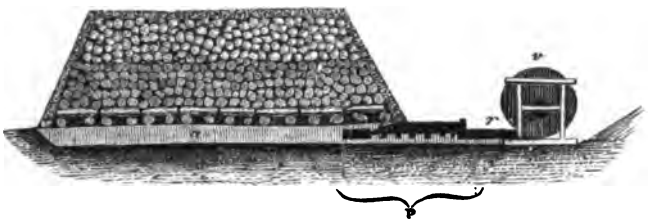
It is evident, from this table, that the amount of combustible matter in equal volumes of charred wood, does not increase after exposure to heat for five hours, whilst a continuance of the heat beyond that time occasions an absolute loss; it is advantageous, therefore, to stop the process before the formation of black meiler-charcoal is effected, a practice which is already becoming general. Wood imperfectly charred, so as to leave in the product the maximum quantity of

Fig. 32.



combustible matter per volume, is called *red charcoal* (*charbon roux*). In France and Belgium, where this kind of charcoal is in use, it is prepared by a kind of meiler carbonization. The meiler is more in the shape of a pile, lengthened out, and erected over a channel *a* formed in the ground, Figs. 32 and 33. The heated gases of a fire, situated at one end at *P*, Fig. 33, are forced, by the motion of a fan *v*, to pass along the channel *r* into *a*, whence they permeate the whole mass of the wood, which thus becomes heated, and undergoes dry distillation. On the outside, the heap is covered with a layer of earth, through which the gases are allowed to escape at those parts to which

FIG. 33.



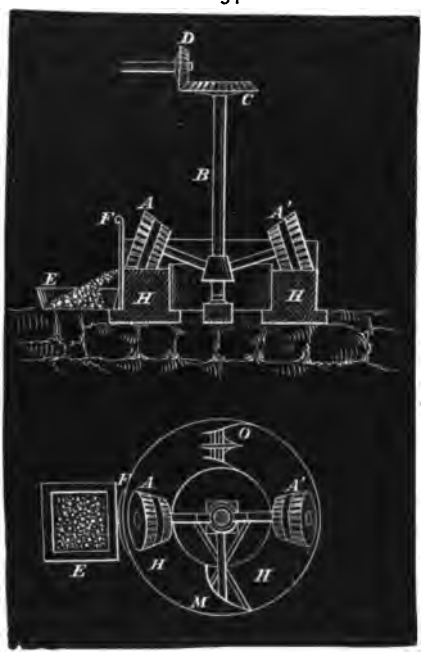
it is desirable to direct the heat. The operation is, therefore, regulated in the same manner as in the meiler with movable covering. The results obtained by Sauvage in this way have not been satisfactory, the wood being either insufficiently charred—in fact, not more than kiln-dried; or if more heat was applied the wood was ignited. The waste gases from smelting or blast furnaces have also been employed in the manufacture of red charcoal, but with no better success. Experience and practice may possibly enable the furnace charring of Schwartz (p. 103) to be so modified as to afford red charcoal of uniform quality, but it appears difficult to adapt Schwartz's principle to meiler carbonization. The introduction of *charbon roux* into a country is of importance, as it effects a great saving in the consumption of wood, the scarcity of which is always on the increase. The great difficulty appears to be in producing red charcoal of uniform quality in large quantities at once. Heated steam has been employed by Thomas and Laurent, and, according to Heyss, de la Croix employed a patent process, both in Belgium and Austria, for charring wood, turf, and coal by means of heated steam. Violette appears to have prepared excellent red charcoal for gunpowder manufacture by this means. Whether, however, the expense of transporting all the wood to a stationary boiler in the neighbourhood of the consumption will not be too great when the charcoal is to be used as fuel appears questionable. Violette's process will be described under GUNPOWDER.

The produce of red charcoal depends entirely on the degree of heat employed in the carbonization. The red charcoal prepared by heated steam for gunpowder-making at a temperature of 300° C. (572° F.) was found to vary from 42 to 36 per cent. of the air-dried wood, according as it was exposed from one to three hours to the heat in the cylinders. Much of the hydrogen and oxygen of the wood are retained by the red charcoal, and, assuming kiln-dried wood as composed of 50 per cent. of carbon and 50 per cent. of water, red charcoal will probably contain about 75 per cent. of carbon and 25 per cent. of oxygen and hydrogen, although these latter are no longer in the relative proportions in which they unite to form water.

The amount of ash is less in red than in black charcoal, a larger quantity of charcoal being obtained from the same weight of wood. The mean quantity is estimated at 1.5 per cent. Red charcoal, being less porous, does not absorb water from the atmosphere with the same avidity as black.

and no experiments have been recorded as to the actual quantity contained in it. Freshly prepared red charcoal ignites much more readily than black, owing to the volatile combustible matters it contains; it produces a long, powerful, and luminous flame, but not equal to that of kiln-dried wood.

Fig. 34.



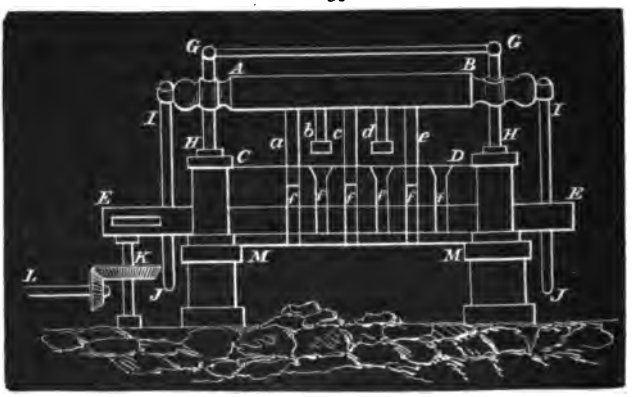
From the very variable nature of red charcoal, it is difficult to arrive at any accurate knowledge of the composition of different qualities; but the following may be assumed as the average composition:—

	Fresh.		Old.
Carbon . . .	74.0		66.5
Oxygen & Hydrogen	24.5	...	22.0
Ash	1.5	...	1.5
Hygroscopic Water	0.0	...	10.0
	100.0	...	100.0

Moulded Vegetable Charcoal.—The manufacture of vegetable charcoal in moulds is a branch of industry which attracted some attention in France, one manufactory producing upwards of 2000 tons per annum in Paris in the year 1859 or 1860. Mixtures of it with animal charcoal and a starchy or saccharine binder are also burned for filter-making.

The raw materials, so to speak, consist of the waste powder from wood charcoal, peat charcoal, twigs, brushwood, charred tan, &c., and tar or liquid pitch.

Fig. 35.

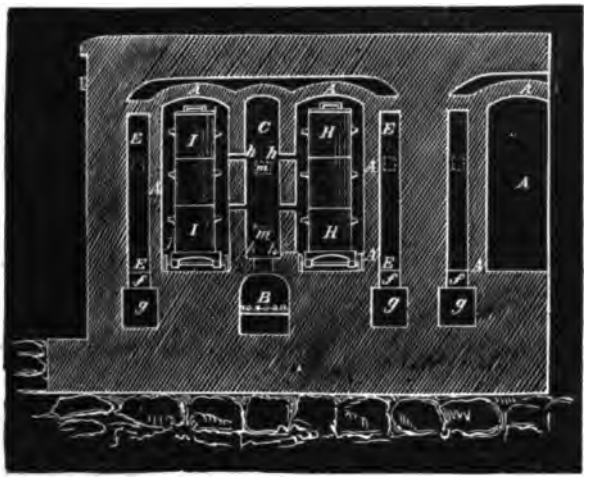


The whole is reduced to a coarse powder between fluted iron rollers, and then thrown on the bed-plate (*HH*, Fig. 34) of a mill, working with a pair of conical fluted stones *A A*, made of cast-iron. The upright shaft *B* is driven by the pinion *D* working into the mitre-wheel *C*. A scraper *O* follows the stones in the usual manner; 7 to 9 gallons of tar are added

to about 2 cwts. of charcoal-powder, which are intimately mixed by the stones, and become a thick, homogeneous paste, which is discharged at the slide *F* by the scraper *M* into a box at *E*. This mill requires one-horse power, and prepares from 6000 to 7000 gallons per twenty-four hours.

The paste is moulded by the machine shown in Fig. 35. A strong wooden beam is raised and lowered alternately by an eccentric motion

Fig. 36.



communicated to the rods *I J*, *I' J'*. Two collars which slide upon two iron uprights *H G*, and *H' G'*, guide the beam *A B*. The iron pistons *a b c d e* of unequal length are firmly attached to the beam *A B*.

Two women are constantly employed filling the funnels *fff* with the paste, which is pressed into the moulds by the pistons *b d*, while the horizontal movement communicated to the metal casting *E E* as shown

Fig. 37.

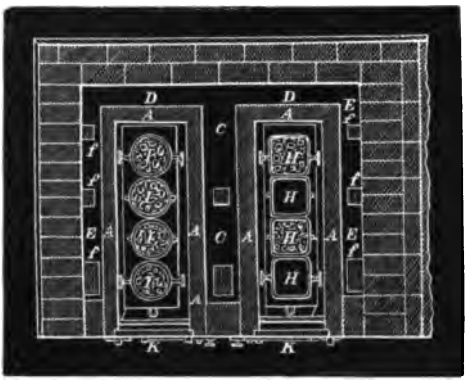
at *L K* immediately carries the full cylinders under the pistons *a c e*, which expel the moulded paste, and thus the operation proceeds continuously.

The power required to work this machine is equivalent to that of six

horses, and it employs one man and four women, who make about 450 bushels of these cylinders per day.

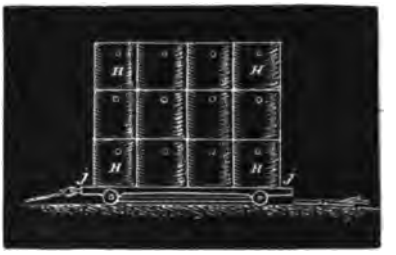
The cylinders are air-dried for thirty-six to forty-eight hours before being exposed to carbonization, which is conducted in a muffle furnace as shown in Figs. 36, 37, and 38. The muffles *A A*, about 4½ inches thick, must be strongly built, and are heated by a fire at *B*. The flame heats the muffles all round, passes behind them through flues *C D*, returns in front by *E*, and finally passes off by the openings *f f* through the underground flues *g g g* to a high chimney at the back.

Fig. 38.



The dry-moulded cylinders, 4½ inches long by 1½ inch diameter, are ranged in two layers in sheet-iron boxes *H H*, or cast-iron cylinders *I I*, and the whole placed on trucks *j j*, Fig. 39, which are then run into the muffles. A metal door *K* (Fig. 37), lined with brick and luted with clay, encloses the whole until the carbonization is complete.

Fig. 39.



The moisture remaining in the moulds, and the carburetted hydrogen, produced by the increasing heat, make their escape through the small flues *h h*, and after the lapse of a certain time, when the cylinders have become red hot, a small current of air cautiously admitted at *m m* ignites these gases. The heat thus produced is sufficient to finish the operation. Two muffles are charged every six hours, and each muffle is filled twice in the twenty-four hours.

Fig. 40.

The cylinders are withdrawn as soon as the flame ceases to appear, which the workman ascertains by opening the air-flue *m*.

The waste cuttings and brushwood which are not adapted for the plan described above, are converted into common charcoal in furnaces shown in Fig. 40, constructed, like coke ovens, of a strong outer wall *E* with an opening *C* at the

top, and another at *A* at the level of the floor. The charcoal is drawn into a pit *f* filled with water. The wood is thrown in by degrees, and drawn every seven hours, or as soon as a flame appears at *C*, which is then immediately made tight by an iron-plate *D*. Each furnace produces about 8 cwts. of charcoal per twenty-four hours, from about 26 cwts. of wood.

The moulded charcoal, being more dense than that made by the old plan, is useful for domestic purposes—it burns longer, and does not lose so much heat by radiation

PEAT CHARCOAL.

Preparation of Peat Charcoal.—Two circumstances are very favourable to the charring of peat in the meiler; first, the rectangular form of the peat bricks, which admits of their being piled up together without leaving those interstices so prejudicial in the wood meiler; and second, as peat charcoal is less combustible, such care and minute attention to the process are not necessary; moreover, the meiler may be constructed of much less circumference, with advantage.

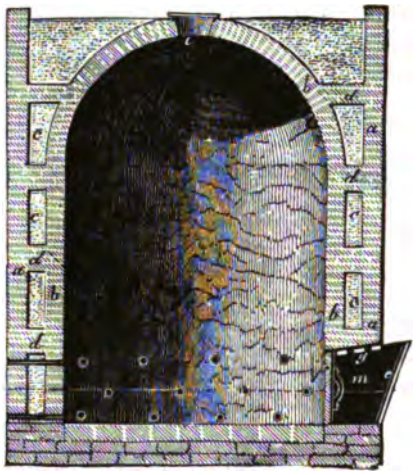
The peat bricks for charring are often cut somewhat larger than those used commonly as fuel, and of these from 5000 to 6000 constitute a meiler, the dimensions of which seldom exceed 10 feet in circumference, containing altogether about 1500 cubic feet. The stake or quandel is erected on a dry spot, and round it the turf-bricks are ranged endwise in concentric circles, diminishing in number as the height increases, so as to give a hemispherical form to the meiler; air-channels, radiating from the centre, of the width of a single brick, being left in all directions to admit air to the interior, which, from the close manner in which the turf packs, would not otherwise be accessible. At the foot of the stake, some dry wood is placed for ignition; the meiler is covered with an inner coating of moss and leaves, and with an outer one of earth or charcoal dust, leaving only the middle part of the hood round the stake uncovered, for the passage of the gases after the meiler is ignited by one of the open channels. By opening and closing these channels, the combustion proceeds in all directions until flame appears at the aperture in the hood, which is then closed, while holes are pierced all round the covering, consecutively from the top to the bottom, at distances of a foot apart, until the charring is completed. The appearance of the smoke issuing from these apertures indicates the stage and state of the operation, which must vary in its management with the age, density, and other physical properties of the peat.

The produce from the mounds has been found to be as follows:—from not quite air-dried peat, 24 per cent. of the weight and 27 of the bulk have been obtained; from air-dried, 27 per cent. in weight and 32½ in volume; from freshly dug Pfungstädt peat, 30 per cent. in weight and 29 in bulk; from excellent peat, quite dry, 35½ of the weight and 49 per cent. of the bulk. In the district of Siegen, very good peat produced 23 per cent. of the weight and 40 per cent. of the bulk. Experiments on a small scale generally afford a still larger produce, sometimes as much as 40 per cent. of the weight. Some difficulty is found in extinguishing the peat meiler; a thin paste of clay and water is found serviceable in accelerating the operation. The peat charcoal is very apt to fall to powder, in which state it is useless as fuel.

Peat Charcoal Kilns.—The use of kilns affords no increase of produce, but a safer regulation of the heat, and is better adapted to peat than to wood, as the former is always obtained on the same spot, and it is not necessary, as in the forest, to follow the clearing or to transport the material. In the manufactory of arms at Oberndorf in Würtemberg, kilns are employed which have stood the test of five years' experience, and have

been approved; one of these is represented in Fig. 41. It is in the form of an upright cylinder, 9 feet in height, and 5½ feet in diameter, closed at the top by a circular arch, and with a capacity of about 200 cubic feet. The kiln itself, *b*, is surrounded by a second wall *a a*, in such a manner as to leave a space *c c*, which is filled with sand, to prevent loss of heat by conduction. Both walls are of brick, each 15 inches thick, the space *c c* being of the same dimensions, so that the entire thickness of the walls is 45 inches. *d d* are stones, placed longitudinally and perpendicularly, to give greater solidity to the walls. Above the sole of the furnace are three rows of draught-holes, formed of pieces of old gun-barrels walled in, which can be readily closed. The door for withdrawing the charcoal is closed by the cast-iron slab *f*; the iron support of the door projects slightly forwards, and in front of it is a deal board *e*, the space *m* being filled with sand from *g*. A space is left in the centre of the kiln for igniting the contents. In the beginning, both the aperture *i*, through which the charge of peat is introduced, and also the lower draught-holes are left open, but as soon as the peat, when viewed through these, appears white hot they are closed, and the upper ones opened. When no more smoke is visible, the apertures are all stopped, or filled with sand, and a layer of sand about 1 foot thick is covered over the aperture *i*; this takes place after about forty to forty-eight hours, when the kiln is left to cool during six or seven days. In order to save time, water is sometimes poured on to the charcoal from the aperture *i*. Ten of these furnaces are worked at the same time, in order to afford a constant supply of charcoal.

Fig. 41.



Peat charcoal, as far as heating power is concerned, ranks among the best kinds of fuel; it possesses, however, at the same time, qualities which render it unfit for many purposes. If 100 lbs. of dry peat leave 21 lbs. of ash, and produce 47 lbs. of charcoal, these 47 lbs. of peat charcoal will contain 21 lbs. of ash, or 45 per cent., which large amount must interfere in many of its applications from its mere bulk, and in others from the tendency it has to fuse and combine chemically with the substances heated in contact with it: while the phosphates and sulphates it contains are objectionable in many metallurgical processes. Those varieties of peat which contain a large amount of ash are, consequently, quite unsuited to the manufacture of charcoal. Another great objection to peat charcoal, is its loose brittle character, which soon causes it to fall to pieces, and become useless; in smelting furnaces, the pressure of the layers of ore suffices to crush it to powder, in which state it so materially obstructs the blast as to derange the entire process; its application is, therefore, confined to boilers, evaporating pans, forge fires, and domestic purposes, whilst even for such it is inferior to kiln-dried peat. This want of firmness has been found to render the charcoal quite incapable of bearing carriage, unless admixed and moulded, and the carbonization must, therefore, be effected on the spot where the charcoal is to be used.

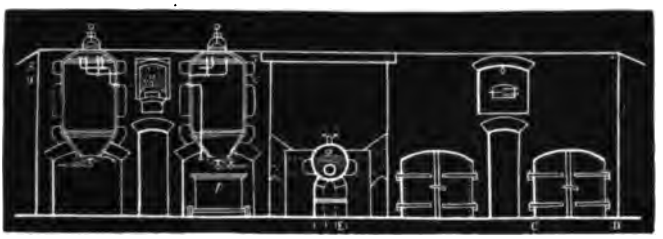
Stones patented a process for compressing peat in boxes, between rollers

in such a manner as to afford hard, square bricks, which are afterwards heated in retorts of wrought-iron, similar, in size and shape, to those used in the manufacture of illuminating gas, with an apparatus for condensing the products of the distillation in a series of receivers so as to separate them to a certain extent without a second distillation; the combustible gases being employed as fuel for heating the retorts.*

Vignoles employed steam, heated to 450° or 460° F. (230° to 236° C.), which is between the melting-points of tin and lead, for charring peat in upright cylinders; the peat having been previously dried, either by a current of hot air produced by a fan driven by the waste steam from the apparatus, or by a hydro-extractor in which centrifugal force is employed to expel the moisture.

Fig. 42 represents a vertical section and partial elevation of the apparatus. *a* represents a section of the large cylindrical steam boiler set over a furnace, the flues from which pass round the cylindrical carbonizing vessels, two of which are shown in the drawing to the left of the boiler and of which there are six on each side, arranged round a central coil of pipes *H*, in which the steam from the boiler *a* can be heated to the required temperature before

FIG. 42.



its admission to the carbonizing vessels. The steam, having passed from the boiler through one department of the red-hot coil, is conveyed into one of the carbonizing vessels; whence, having sufficiently charred the peat, it passes through another part of the coil into the next, and so on, until having passed through all six it is employed to work a low-pressure engine, which drives a fan, the current of air from which is heated, by passing through pipes, to 250° F. (121° C.), before it is admitted into chambers where the moist peat is exposed to dry.

The cylindrical carbonizing vessels are composed of boiler-plate, conical at the bottom, where they are furnished with a steam-tight man-lid or door for removing the charred peat, a similar door being fixed in the dome-shaped upper part for its introduction. The charred peat, if exposed to the air, would be liable to spontaneous combustion; it is discharged, therefore, into iron cooling-boxes *p* placed below the carbonizing cylinders, and low-pressure steam is blown once or twice through it.

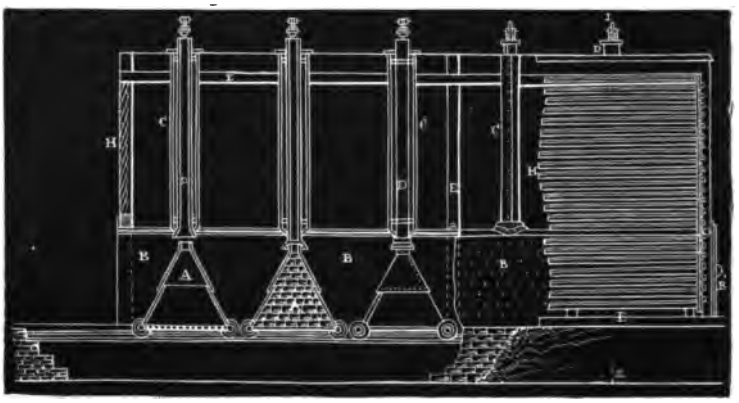
Rogers carried out a system of drying and charring peat in Ireland, the principle of which will be seen by reference to Figs. 43 and 44. A long shed, shown in longitudinal section *E E*, Fig. 43, is constructed over a sunk channel or ash-pit, traversing its entire length and built with bricks, on the margin of which a railway is laid down to enable small travelling chambers or kilns *A* to travel easily through the shed and over the ash-pit.

The kilns *A* are made of sheet-iron on a framework of iron with wheels, the bottoms being constructed of bars which serve as a grate. They are filled with the peat to be charred by inverting them, and then inserting the grate. The interior part of the shed, through which these travelling ovens

* "Rep. Pat. Invention," 17, 16; 19, 220.

pass, is formed into a kind of chamber by sheet-iron plates *B B*, through which, at regular intervals, are pipes *D D* leading to the top of the shed. Within these vertical pipes are placed other movable pipes which fit on to the tops of the kilns and perform the part of chimneys; they can be moved

Fig. 43.



up and down sufficiently to admit the upper part of the kilns to pass below them. The sides of the shed are filled up with lattice-work shelves for the reception of the air-dried turf-bricks, and the slanting sides are protected from the rain by movable louvres *H H*, Fig. 44, which can be opened or closed at pleasure, and when supported by a few sods of turf below, serve as stepping-places for the workmen when employed in filling or emptying the shed. When the shed is packed, and the kilns are filled with turf and arranged under their respective chimneys, these latter are opened at *d* by the rod *e*, and the turf is ignited from below by the ash-pit. The charring is then carried on as in other furnaces of similar construction, a portion of the turf being consumed in charring the remainder, and the draught is regulated by the flue-door at *d* and the ash-pit door below. The heat from the kilns is thus made to dry the turf in the shed, and its action is sometimes augmented by a current of air forced through the house by a fan.

Fig. 44.

Green produces a hot draught of air through a drying-house by means of chimneys and fires, and then distils the dried peat in wrought-iron cylinders placed in pairs over a furnace, and similar to those employed in making illuminating gas, the gases from the turf being consumed as part of the fuel below the retorts.

LIGNITE CHARCOAL.

Of all kinds of fuel, brown coal or lignite is least adapted for carbonization, although it is decomposed with as much ease as wood, and the charcoal which it produces is not so easily inflammable. The previous remarks on the ash of peat apply with equal force to brown coal, but even the best

kinds of brown coal are not easily charred, as, during the action of the heat, the single layers, concentric rings, &c., which are scarcely perceptible in the fresh specimens, split off, and a compact piece of brown coal becomes thus completely broken up into small fragments, or so fissured as not to bear carriage. Roschers states that lignite, if thoroughly air-dried when fresh from the pit and very slowly charred, is not subject to this disintegration; and, according to Mayer, very firm charcoal is obtained by charring the freshly dug lignite without previously exposing it to the air. In experiments with lignite from the Hessenbrücker Hammer (in the Wetterau), 15½ per cent. by weight and 32 per cent. by volume were obtained by meiler carbonization. This quantity is too small to pay for the cost of manufacture.* In the neighbourhood of Cassel, where circumstances are more favourable, the carbonization in mounds has been actually carried out, but only upon a small scale.

Good charcoal is rarely obtained from brown coal; as a rule, it is friable and pulverulent, and difficult to quench when just carbonized.

Experiments made with brown coal on a small scale, in which the coal was heated in close crucibles, until all vapours ceased to be evolved, gave the results shown in the following table:—

	100 parts.	Charcoal. Per cent.
Bohemia, Left side of the Rhine, near Düren	Earthy coal from Dax	49.1
	,, ,, Bouch. d. R.	41.1
	,, ,, Basses-Alpes	48.5
	Lignite from Greece	38.9
	,, Cologne	36.1
	,, Iceland	57.5
	,, Raddergrube	41.6
	,, ,,	49.7
	,, Gr. Urwelt	44.3
	,, ,,	43.9
	,, ,,	51.3
	,, Friesdorf	28.2
	,, ,,	48.2
	,, ,,	46.8
	Earthy coal from Uttweiler	68.2
	,, ,, Raddergrube	48.3
	,, ,, ,,	46.4
Bohemia, Right side, near Bonn	Lignite from Pützchen	46.4
	,, ,,	44.7
	,, ,,	51.0
	,, Stösschen	29.1
	,, ,,	40.6
	,, Orsberg	62.8
	,, ,,	68.4
	,, Aussig	40.1
	,, ,,	40.0
	,, Hegendorf	41.2

	100 parts.	Charcoal. Per cent.
Bohemia	Lignite from Neundorf	38.4
	,, Coulang	38.1
	,, Jahnsdorf	32.8
	,, Paredel 1	39.6
	,, ,, 2	40.7
	,, ,, 3	42.0
	,, Antoni-Zeche	40.0
	,, Wellonitzer Br.	35.9
	,, Nemtschauer Br.	34.7
	,, Hartenberg 1	37.2
	,, ,, 2	34.6
	,, Kanden	37.5
	Pitch coal from Grünlat	37.2
	Earthy ,, Hartenberg 1	42.1
	,, ,, ,, 2	48.4
	,, ,, ,, 3	36.8
	,, ,, ,, 4	39.0
	Pitch ,, ,, 1	43.9
	,, ,, ,, 2	40.3
	Earthy ,, Soaz	46.4
	Pitch ,, Richenau	38.1
	,, ,, ,,	29.3
	,, ,, Altsattel	40.3
	,, ,, ,,	35.0
Bavarian Oberpfalz	Earthy coal from Verau	35.6
	Lignite ,,	46.0

CARBONIZATION OF PIT COAL.

In some Scottish localities, in the neighbourhood of trap dykes, coal is found to have been changed to coke ("carbonite"). Similar effects have been noticed (1882) in Midlothian, Chesterfield Co., Va., where the carbonite seam is 15 feet thick. The American mineral is reported to contain about 80 per cent. fixed carbon, 3.2 to 6.7 per cent. of ash, and 1.6 to 4.1 of sulphur; it much resembles anthracite.

* One cwt. of coal costs 5¾*d*, one cwt. of charred coal about 3*s.* 11*d*

General Principles.—The products formed during the charring of coal, although similar in kind, differ considerably from those obtained under the same circumstances from wood. This might reasonably be anticipated, from the different elementary composition of the two substances, the dissimilar arrangement of their elements, with the addition of nitrogen and sulphur (partly organic, and partly as pyrites), and the higher temperature required to complete the carbonization; the nature of the products very much depends on the temperature employed. In addition to the solid coke as residue, both liquid and gaseous compounds are produced; the former being differentiated into an aqueous and oily portion, the latter containing many of the compounds found in wood-tar, but also numerous other substances, which will be described in another place. As a general example of the products obtained in the dry distillation of coal, and their relative quantities, the following analysis, in the course of which coal was submitted to a slow distillation in a close vessel, may be adduced:—

	Coke	68.925	
Liquid products	Tar	12.230	= 19.799
	Water	7.569	
Gaseous products	Marsh Gas (CH_4)	7.021	= 11.276
	Carbonic Oxide	1.135	
	Carbonic Acid	1.073	
	Olefiant Gas (C_2H_4)	0.753	
	Sulphuretted Hydrogen	0.549	
	Hydrogen	0.499	
	Ammonia	0.211	
	Nitrogen	0.035	
		100.000	

The relative quantities of these products, as well as the nature of the tar and water, vary with the temperature employed. When the charring goes on with access of air, a portion of the coke as well as of the gaseous products of distillation is consumed in carbonizing the remainder.

The following table of the products of the destructive distillation of coal is taken, with the author's sanction, from the recent third edition of Professor Mills's "Destructive Distillation." Boiling-points and melting-points are given, so far as known.

PRODUCTS OF THE DESTRUCTIVE DISTILLATION OF COAL.

Name.	Formula.	B.P.	M.P.
		Deg. C.	Deg. C.
Hydrogen	H_2	−215	
Methylic Hydride (Marsh Gas)	CH_4	−144 (?)	
Hexylic "	C_6H_{14}	+ 68	
Octylic "	C_8H_{18}	119	
Decylic "	$C_{10}H_{22}$	171	
Paraffins	C_nH_{m+2}	< 554	
Ethylene (Olefiant Gas)	C_2H_4	−103	
Tritylene	C_3H_6		
Tetrylene	C_4H_8	5	
Pentylene	C_5H_{10}	+ 31	
Hexylene	C_6H_{12}	71	
Heptylene	C_7H_{14}	97	
Acetylene	C_2H_2	−210 (?)	
Crotonylene	C_4H_6	+ 25	
Terene	C_5H_8		
Hexoylene	C_6H_{10}	80	
Styrolene	C_8H_8	145	
Thiophene	C_4H_4S	84	
Thiotoluene	C_7H_8S	113	
Benzene	C_6H_6	80	5.17
Parabenzene		97	
Tolnene	C_7H_8	111	

DESTRUCTIVE DISTILLATIO N OF COAL—(*continued*).

Name.	Formula.	B.P.	M.P.
		Deg. C.	Deg. C.
Xylene (ortho)	C_8H_{10}	143	
,, (para)	,,	137	
,, (meta)	,,	137	
Cumene	C_9H_{12}	166	
Mesitylene	,,	163	
Cymene	$C_{10}H_{14}$	166	
Terpene	$C_{10}H_{16}$	171	
Naphthalene	$C_{10}H_8$	218	80
Methylnaphthalene	$C_{11}H_{10}$	242	− 18
Naphthalene Hydride	$C_{10}H_{10}$	—	+210
Phenyl	$C_{12}H_{10}$	254	70
Acenaphthene	,,	285	100
Fluorene	$C_{13}H_{10}$	295	113
Phenanthracene	$C_{14}H_{10}$	340	99
Anthracene	,,	360	213
Fluoranthrene	$C_{15}H_{10}$	—	109
Pyrene	$C_{16}H_{10}$	—	148
Anthracene Hydride	$C_{14}H_{12}$	305	106
Methylanthracene	$C_{15}H_{12}$	—	200
Chrysene	$C_{18}H_{12}$	—	249
Retene	$C_{18}H_{18}$	350	99
Picene (?)	$C_{22}H_{14}$	519	338
Water	H_2O	100	0
Hydric Sulphide	H_2S	—	− 85
,, Cyanide	HCN	26	18
,, Thiocyanate	HCNS		
Carbonic Oxide	CO	− 193	
,, Dioxide	CO_2	78	
,, Bisulphide	CS_2	+ 47	110
Sulphuric Dioxide	SO_2	− 10	
Hydric Acetate	$C_2H_4O_2$	+120	+ 15
Acetonitril	C_2H_3N	77	
Ethylic Alcohol (?)	C_2H_6O	78	−130.5
Phenol	C_6H_6O	182	+ 42
Cresols, − o, m, p	C_7H_8O	118, 201, 199	31 (?), 36
Pyrocresols, α, β. γ	$C_{28}H_{24}O_2$	—	104, 124, 195
Phlorol	$C_8H_{10}O$	219	
Ammonia	NH_3	− 33	− 70 (?)
Butylamine	$C_4H_{11}N$	75·5	
Aniline	C_6H_7N	182	8
Cespitine	$C_8H_{11}N$	96	
Pyridine	C_5H_5N	115	
Picoline	C_6H_7N	134	
Lutidine	C_7H_9N	154	
Collidine	$C_8H_{11}N$	170	
Parvoline	$C_9H_{13}N$	188	
Coridine	$C_{10}H_{15}N$	211	
Rutidine	$C_{11}H_{17}N$	230	
Viridine	$C_{12}H_{19}N$	251	
Acridine	$C_{11}H_9N$	360	+107
Carbazol	$C_{12}H_9N$	355	238
Phenylnaphthylcarbazol	$C_{24}H_{17}N$	—	330
Leucoline, α, β	C_9H_7N	220, 238	
Lepidine, α, β	$C_{10}H_9N$	254, 268	
Iridoline			
Cryptidine	$C_{11}H_{11}N$	272	
Tetracoline	$C_{12}H_{13}N$	292	
Pentacoline	$C_{13}H_{15}N$	312	
Hexacoline	$C_{14}H_{17}N$	327	
Heptacoline	$C_{15}H_{19}N$	347	
Octacoline	$C_{16}H_{21}N$	362	
Pyrroline	C_4H_5N	133	
Carbon (Hydrogenated)	C_n		
Sulphur	S_2	400	115
Nitrogen	N_2	− 194	−213 (?)

The residue, after the action of heat on pit coal, is commonly called *coke*. Coals may be subdivided with reference to the production of coke into two classes, the *coking* and *non-coking*; the small of the latter is useless, unless mixed by mechanical means in certain proportions with the small of the coking coal, as was proposed by the late Mr. Budd of Ystalyfera.

On the Continent, those who have examined coal with reference to the property of coking prefer to classify it under the heads of *caking*, *sinter*, and *sand coal*.

Caking or coking coal is that variety which, when strongly heated, undergoes a kind of semi-fusion while parting with its volatile ingredients, the separate pieces caking together to form one solid mass.

Sinter coal approaches nearest to caking coal, but the fusion of the separate pieces into one is not so perfect.

Sand coal produces coke that retains the form of the original coal without caking.

These varieties are distinguished from each other and from anthracite by their elementary composition, on which, indeed, their coking properties very much depend. This will be seen by reference to the following list, which shows the mean composition of the organic portion of the varieties of foreign coal, the analyses of which were given on a former page (53), and which are arranged according to the above classification:—

	Carbon.	Hydrogen.	Oxygen.
Sand coal	77	5	18
Sinter coal	83	5	12
Caking coal	87	5	8
Anthracite	95	3	2

It will be observed that the amount of hydrogen in the first three varieties is identical, whilst the oxygen diminishes as the property of caking is developed; but this is lost when both oxygen and hydrogen are very much diminished. An excess of hydrogen, however, which has been supposed by some to be chiefly instrumental in imparting the caking property to coal, is not alone sufficient to account for this property in all cases, as will be more clearly seen by some analyses made by Regnault expressly to determine this point, and in which great attention was paid to the character of the coke obtained from each variety of coal. The analyses alluded to have been given in detail in the former tables: we have here calculated formulæ from them, assuming the same quantity of carbon in each in order to show the relation of the other elements more distinctly.

		Relation of H to O.
Anthracite from Balduc, sand coal	$= 80C + 88H + O$	88 : 1
Coal from Blanzy, sinter coal	$= 80C + 128H + 6O$	21 : 1
Cannel coal from Lancashire, sinter coal	$= 80C + 128H + 3O$	43 : 1
Coal from Mons (flénû), caking coal	$= 80C + 240H + 5O$	48 : 1
Coal from Grand Croix (maréchal), highly caking	$= 80C + 112H + 3O$	37 : 1

It will be seen that the property of caking generally increases with the quantity of hydrogen and oxygen, particularly with that of the hydrogen. Anthracite, consisting almost entirely of carbon, may be viewed as a kind of natural coke; the quantity of hydrogen rises in the others in proportion as they soften in the fire, with the exception of the last, which possesses this quality in the highest degree, although its hydrogen amounts to only half the quantity contained in the caking coal from Mons.

The same fact has been remarked with the younger coal of Obernkirchen, which is also of a highly caking character. It also produces a porous, friable coke, and has the composition $80C + 104H + 3O$ or $O : H = 1 : 35$.

Dr. Percy has shown that the amount of "disposable hydrogen" may

be the same both in caking and non-caking coal. It may, however, be observed that, in the case of curly cannel from Leeswood Green Colliery, Flintshire, when the disposable hydrogen much exceeds about 4½ per cent., the caking property disappears. Finally, Stein of Dresden has shown that caking coal and non-caking coal may both have the same ultimate composition. On the whole, it appears probable that, whilst "disposable hydrogen" doubtless confers fusibility, the real source of caking lies in a resinoid body or bodies, identical in composition with coal itself.

Desulphurization.—The production of coke is undertaken with the same general object in view as the production of wood charcoal; but it is desirable, for many purposes, to free the coal from sulphur. In this sense, the production of coke may also be called a desulphurization of coal, but it has been also found necessary to attempt the removal of sulphur remaining in the coke.

Desulphurization of Coke.—The subject of the various processes for the desulphurization of coke has been investigated by A. Philippart, a Belgian engineer (*Revue Univ. des Mines, &c.*, 1871, xxviii. 261–318), with the result that none of the methods which he examined has succeeded on a practical scale. Indeed, as to most of them, Dr. Percy remarks that the term desulphurization is improperly applied, inasmuch as their object is not the *elimination* of sulphur, but merely its transference from the iron (of pyrites), in combination with which it usually exists in coke, to some other substance so as to form a combination not injurious in subsequent operations, such as smelting.

The various methods proposed for desulphurization during coking are:

I. Heating the coke to redness in a current of steam.

II. Heating the coke to redness in a current of air under ordinary pressure.

III. Heating the coke to a lower temperature than redness in a current of air under increased pressure.

IV. Mixing common salt with coal previous to coking, or the use of a solution of chlorides added to the coal during coking.

V. Mixing other substances, such as carbonate of soda, lime, carbonate of lime, or oxide of manganese, with the coal previous to coking.

VI. Coking with common salt, and subsequently washing the coke.

I. The method of applying steam to coke during coking, or before the coke is drawn, was patented by Claridge and Roper in 1858. They proposed to use in the coke oven a false perforated bottom, underneath which, at any time during the process of coking, steam could be admitted and made to ascend through the coke. Scheerer (*B. u. H. Zeitung*, 1854, xiii. 239) had, however, published in 1854 the results of an experiment in which high-pressure steam was passed into an oven before drawing the coke. The coke thus treated was found to have lost 0.4 per cent. of sulphur.

Philippart's experiments with this process gave the following results:—

State of Combination of Sulphur	Percentage of Sulphur	
	Before Desulphurization.	After Desulphurization.
As Sulphide	0.575	0.450
„ Sulphate . „ . .	0.050	0.040
	0.625	0.490

II. This process was experimented on by Philippart, with the result that in one case 10 per cent. of the total sulphur was converted into sulphurous acid, but the loss of carbon by oxidation amounted to 55 per cent. In

another case 30 per cent. of the total sulphur was converted into sulphurous acid, and 18 per cent. of carbon was lost by oxidation.

III. In experiments made with air at 2 to 2½ atmospheres (the coke being heated to between 250° C. and 300° C.) it was found that only 7 per cent. of the total sulphur was eliminated, but the loss of carbon was not so great as with air at atmospheric pressure.

IV. This was the process of the late Prof. Crace Calvert of Manchester, his object apparently having been to form volatile compounds of sulphur and phosphorus with the chlorine of the common salt.

Calvert sent to Dr. Percy the results of an experiment in which coke prepared without salt from a North Staffordshire coal contained 2.56 per cent. of sulphur, whilst with salt from the same coal the coke contained only 0.72 per cent. Philippart's experiments with this process gave the following results:—

No. of Coal.	Percentage of Sulphur		
	In the Coal.	In Coke without Salt.	In Coke with 10 per cent. Salt.
I.	0.50	0·45	0.475
II.	4.25	2.30	2.25
III.	0.50	0.465	0.675

V. The use of these other substances has resulted merely in fixing the sulphur and providing an agent to neutralize its bad effects in iron smelting, &c. They have not been employed on the large scale.

VI. In order to avoid fixing the sulphur in the coke by forming sulphites and sulphates, T. Rowan patented in 1868 a process of coking coal (or calcining ore) with salt, and subsequently washing the coke (or calcined ore) by immersion in water. This process gave some promising results in experiments both with coal and with ironstone, but it has not been introduced on a large scale.

The fact that the bulk of the sulphur found in coal exists in the form of iron pyrites (or "brasses") which may readily be removed by washing, providing the coal has been sufficiently broken or crushed, has led to the gradual introduction of this method of cleansing the coal—the more so, as other impurities, such as shale and slate, are also removed by the same process, and the effect of crushing the coal is to produce a more uniform and dense quality of coke.

Sulphur not present as sulphate or as pyrites is termed "organic sulphur," because it is believed to be in a state of combination with carbon and hydrogen. It is probable that, when adequate heat is applied to coal, the whole of this sulphur distils off, at an early period, in combination with hydrogen. The organic sulphur of coal has been but very little investigated.

Iron pyrites is one of the most injurious mineral ingredients of coal, as the sulphur in it is far from being completely removed by the operation of coking, whilst the oxide of iron which remains in the coke forms with silica from the ash a slag or scar when the carbon is consumed. This scar, covering the grates of a locomotive furnace, for example, prevents the free access of air, and consequently wastes the fuel, as the latter is to a much greater extent converted into carbonic oxide, instead of being completely oxidized; this diminishes the speed by arresting the rapid production of steam. It has been found in practice, therefore, that a coke which leaves a white ash, although this may be twice as much as in the case of another yielding oxide of iron, is much superior for locomotive purposes. Fortunately, this constituent of certain cokes actually renders them more adapted for smelting

some lead-ores than the others; as, for example, on the east coast of Spain, where the oxide of iron acts as a precipitant for the lead in the furnaces.

COAL-WASHING MACHINES.

As the presence of sulphur or pyrites is so injurious where coke is employed for locomotives, in re-melting iron for foundry purposes, or in the manufacture of iron in blast furnaces, it is becoming the practice pretty generally to remove pyrites and other impurities from the coal by mechanical means, which are also employed for cleansing dross which is to be used without being made into coke, and small coal which is to be made into briquettes or into patent fuel. This is effected by various methods of washing the coal, all of which depend for their action on the difference between the specific gravity of the coal and that of the mineral impurities which it contains.

Apart from modifications in structural details, these machines may be divided into two classes—viz., those which operate by agitation of the water produced by the movement of a piston, and those which act on the principle of the sluices used in washing auriferous and other ores.

The piston machines have the advantage of economizing the quantity of water used, but only a few of them carry this to the point of using the same water over and over again.

Some of the best-known plans are shown in the following illustrations:—

Fig. 45.

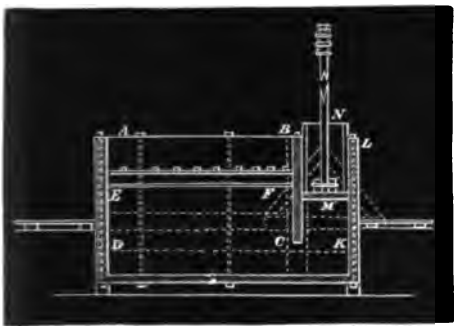


Fig. 46.

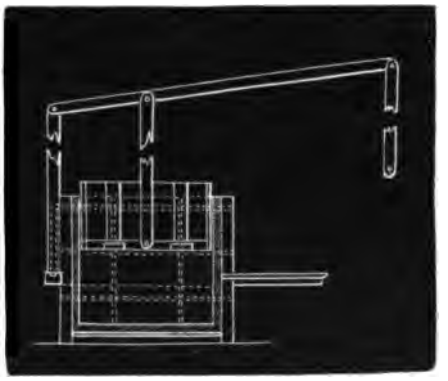


Fig. 47.

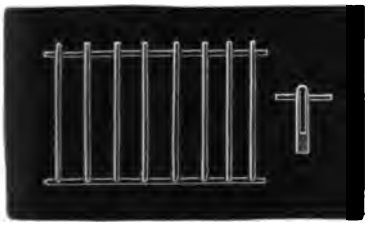
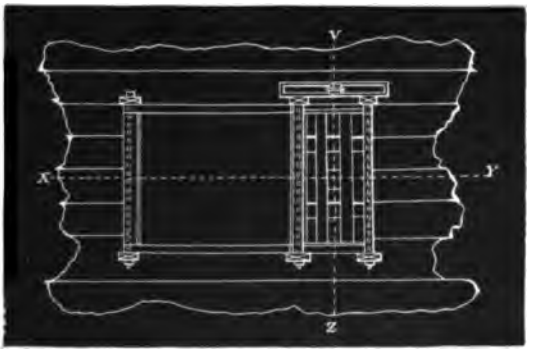


Fig. 48.



Figs. 45, 46, 47, 48, show designs of a piston cylinder for washing the coal.

A B C D, compartments for the grate.
E F, grate on which the coal rests.
G H, bars below which the shale accumulates.
B K C L, compartments for the piston *M N*.

Fig. 49.

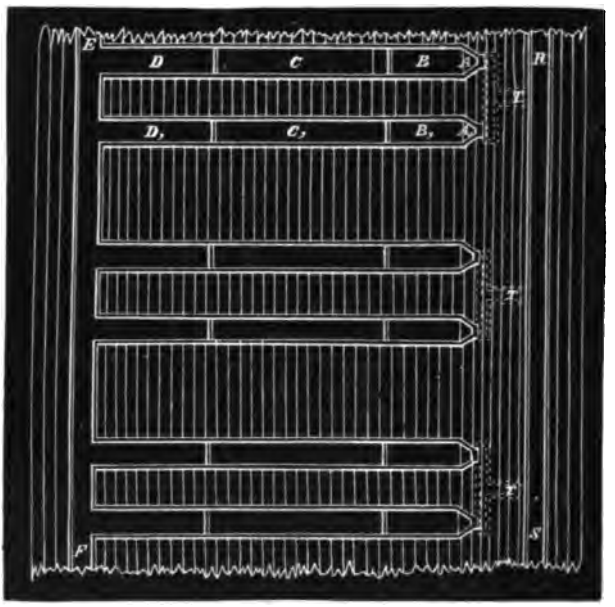


Fig. 50.

Figs. 49 and 50, plan and section of the sluicing process employed at Commentry.
R S, channel for conveying the water to the washing place.
T, channel intended for the washers *A B C D* and *A, B, C, D*,
A A, sluices for regulating the admission of the water.
B C D B, C, D, three distinct compartments for washing.
E F, exit for the water.

Fig. 51.

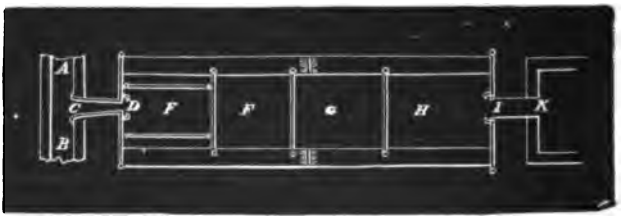


FIG. 52.

Figs. 51 and 52, plan and section of the sluicing washers at Felessin.
A B, general canal for conveying the water to the apparatus.
C, regulating sluices.
C D, canal for admitting the water.
E, first compartment, where the stones are deposited.
F G H, other compartments.
I, the point where the steel division is placed to retain the coal.
K, exit for the water.

The general results are said to be that three workmen, during the twelve hours, can wash 11 to 15 chaldrons, and the produce is in 100 parts:

Washed coals	89
Shale	2
Small coal	9
	100

whilst the quantity of ash in the coal has been reduced nearly one-half. The small coal contains 20 to 25 per cent. of ash. The cost may be calculated from the French data, as follows:—

	d.
Labour	5.1
Other charges	1.2
Loss	8.3
	14.6

or about 1*s.* 2*d* per ton of washed coals, which, on a produce of 66 per cent. of coke, would make the cost 1*s.* 10*d.* per ton of coke.

MEYNIER'S coal-washing machine consists of a force-pump of large diameter, connected with a chamber of wrought iron, into which water is forced and made to ascend through a heading of wood pierced with holes, so as by continued movement the cleaner portions of the coal are made to flow to the upper portion of the wrought-iron chamber, and thence over the lip on to a curved drainer (as shown in plan Fig. 53), from whence they are raked on to a paved platform and filled away.

The drainer may be made either of wire gauze or of perforated iron, supported in its place by iron bars, and the water which goes to the channel below it can flow round the pump and be lifted again if necessary.

Between the force-pump and machine, there is a slide valve to regulate the flow of the water, and branch pipes are shown in plan and section (Fig. 53) by which the other chambers requisite may be supplied in a range of washing machines.

Between each alternate machine is placed a mitre valve to allow the pyrites and dross to descend into the chamber below it, from whence it can be cleaned out as it accumulates.

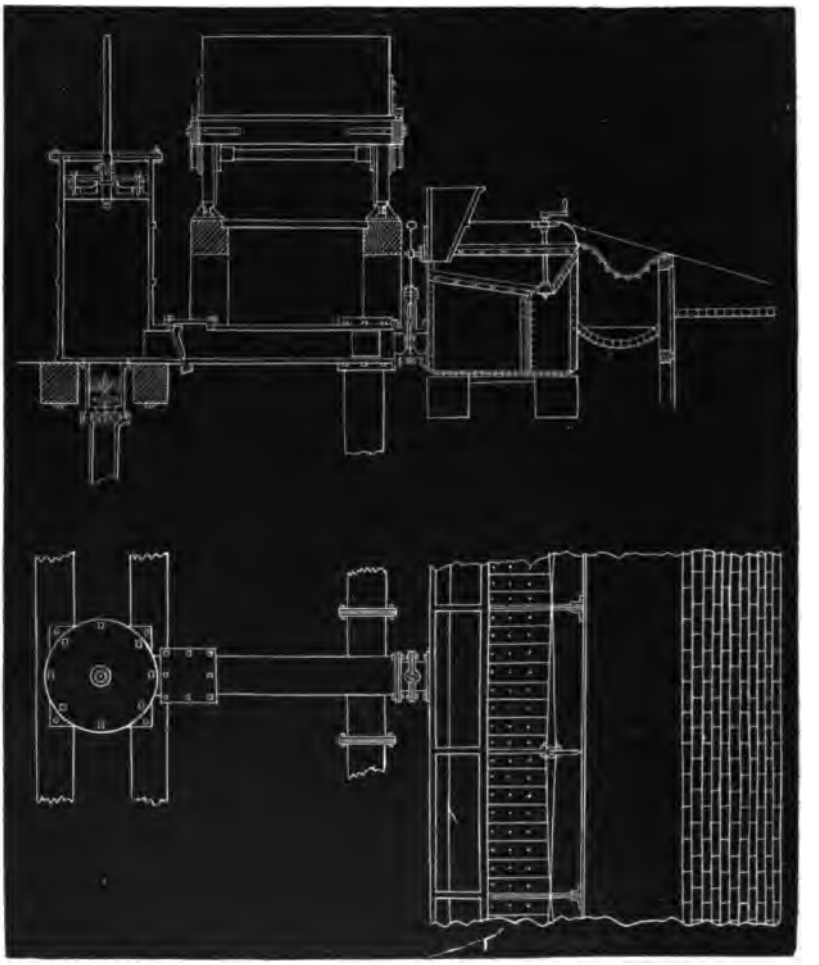
The motive power is not shown, but it may be either steam or water.

The cleading ought to be inclined towards the mitre valve, as shown on the plan, so as to facilitate the descent of all substances of superior specific gravity to coal itself to that point.

About 2 inches from the upper surface of the coal, when the machine is full, iron bars are placed so as to admit of a plank being placed on them, by means of which an operator can reach any part to clean or arrange it during the progress of the work.

The flow of water can be further regulated, in the case of the pump being larger than the requirements, or machines in use, by having an escape valve loaded to such a pressure as the work requires.

Fig. 53.



The spouts for feeding the coal ought to be so placed as to cause the coal to pass regularly over the cleading, and subsequently be submitted to the action of the water.

The arrangement as shown is for an ordinary truck, similar to those used in the Midland Counties traffic; but this can be modified according to circumstances.

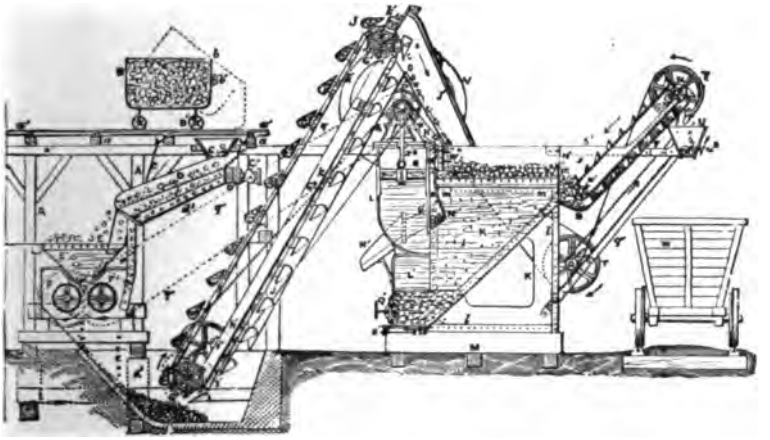
Bérard's machine was exhibited in London at the Exhibition of 1851, and also in Paris in 1855, and received awards. It carries out the following operations:—

1. Sorting the coal by throwing out the larger pieces.
2. Breaking up the pieces which are too large for washing.
3. Continuous purification of the coal.
4. Loading the washed coal into waggons.
5. Loading the refuse (pyrites, schist, or slate) into waggons for removal.

A machine to operate on 80 to 100 tons of coal per twelve hours requires from four to five horse-power.

Fig. 54 illustrates this machine.

FIG. 54.



The coal to be washed is run on to the staging *A* by trucks *B*, or is raised by elevators and delivered on to the table or movable grating *D*, which is formed of a series of sloping plates, each plate perforated with holes of a smaller size than the one above it. These gratings are suspended by rods, and have a motion and concussion given to them by cam mechanism, so that the coal is quickly sorted according to its different sizes, which are delivered at different levels.

The larger pieces, which do not penetrate the perforations in the first plate reach the picking-table *E*, where stones, fragments of iron, and the like are picked out by hand. Those pieces which have passed through the first plate, and are retained by the next, are delivered to the crushing-rollers *F F'*, while the finer portions, which have passed through the second plate, fall directly by the shoot *e* into the pit *A'*, where the coal which is passed through the crushing-rollers also accumulates. It is raised from this point by an endless band with elevators *J*, and delivered by the shoot *j'* to the perforated table *m'*, which is placed above the inclined side of the well *L*. This side is inclined at an angle of 45°, and on the opposite side is a cylinder *O*, in which a piston works. The bottom of this cylinder communicates with the well *L*, at about half the height of its vertical side, and the downward motion of the piston causes the water which fills the well and cylinder to rise through the perforated table *m'*, in its upward current lifting and floating the particles of coal, while the dirt settles down or is washed off elsewhere.

The washed coal is delivered by elevators *T* to a sorter *U*, from which it is filled into waggons according to its size.

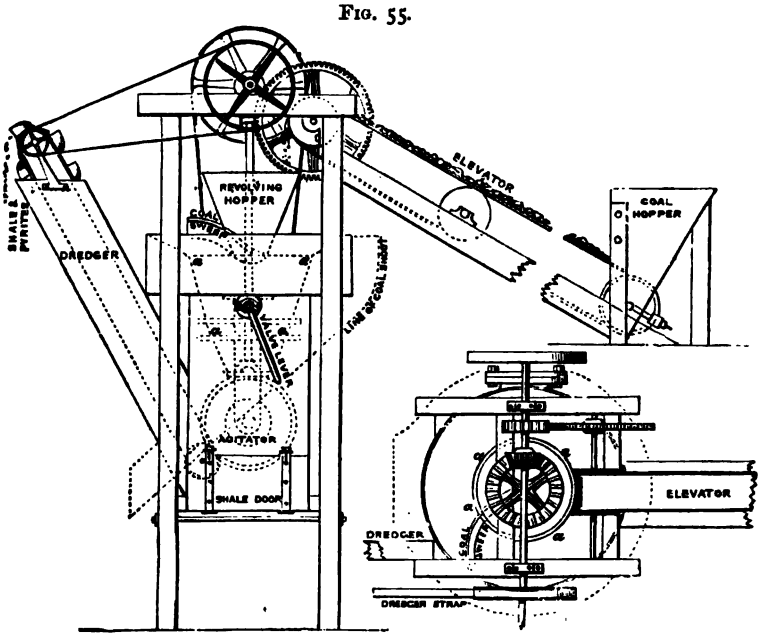
MACKWORTH'S purifier is illustrated in Fig. 55.

The water in it is said to have been made to ascend with a speed of 1 to 2 inches per second, in order that a smaller area of separator could be used than in other machines.

In working this machine, coal is tipped into the coal-hopper, whence it is conveyed by the elevator in a continuous stream into the revolving hopper of the machine. As the coal is washed, it is raised out of the water by a perforated plate, and delivered by the coal-sweep into a perforated shoot, which conducts it to waggons, allowing the water to drip through the perforations. The shale and other impurities collect in a shale-box at the bottom of the machine, and are discharged by an elevator or dredger into suitable waggons. The pump or agitator is capable of throwing from 50 to 200 gallons of water per minute, according to the size of the machine. An endless belt is shown, without buckets, conveying the coal from the hopper into which it is tipped to the machine.

By means of the revolving hopper, the coal passes gradually down into the separator, where a current of water is driven upwards through the mass of shale and coal, at a velocity of from 4 to 5 feet per minute, by the agitator or screw. This water passes back again by the finely perforated

FIG. 55.

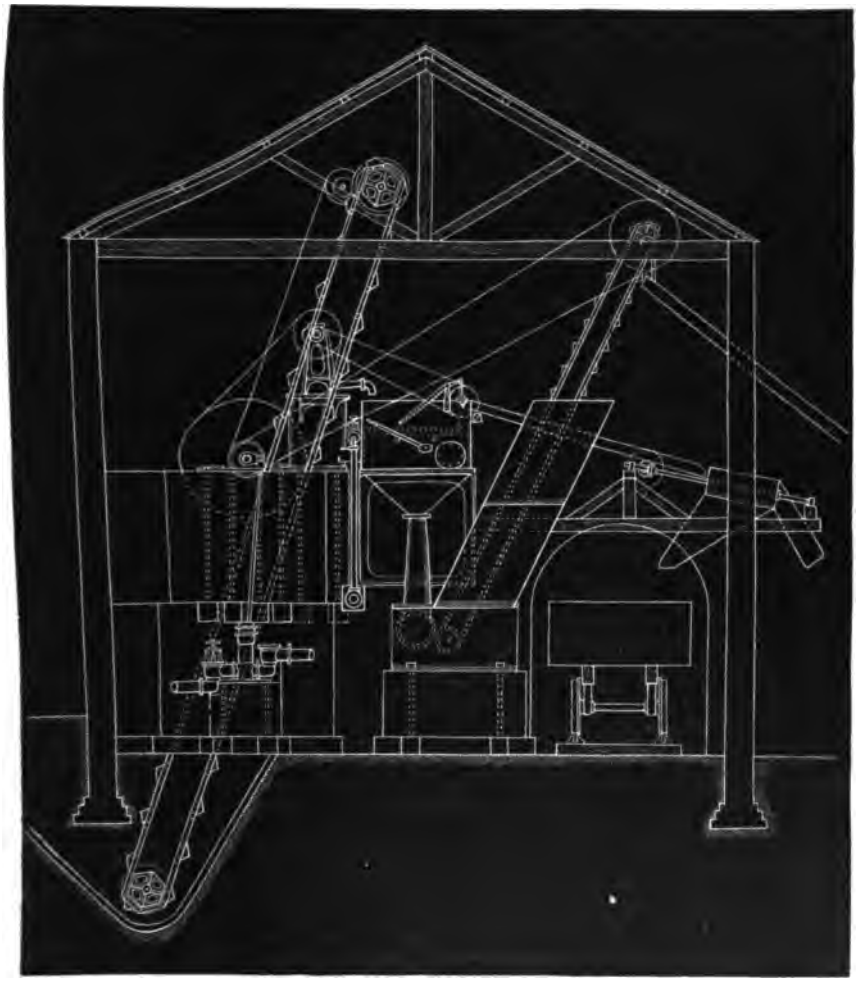


plate, and, with the fine silt suspended in it, is again driven upwards by the screw to undergo a repetition of the process. The gentle agitation produced by this current separates the shale and pyrites from the coal in the separator; the impurities descend through the valves and are taken up by the dredger, while the coal is pushed out of the water by the curved arm or sweep; as soon as the water has drained off, the coal falls on to the shoot, which conducts it to the waggon. A brush following the arm helps to keep open the holes in the perforated plate. The valves remain constantly more or less open according to the indications given by the dredger, and are regulated by the valve lever. The water required to replace what is absorbed by the dry coal and shale enters by the hopper, and flows slightly inwards through the shale valves as the shale is coming out.

It is said that machines were started in Scotland, Cumberland, Derbyshire, Gloucestershire, and Wales, to purify from 20 to 100 tons of coal per day, at a cost not exceeding 3*d*. per ton, and with a loss not exceeding 2 per cent. of coal.

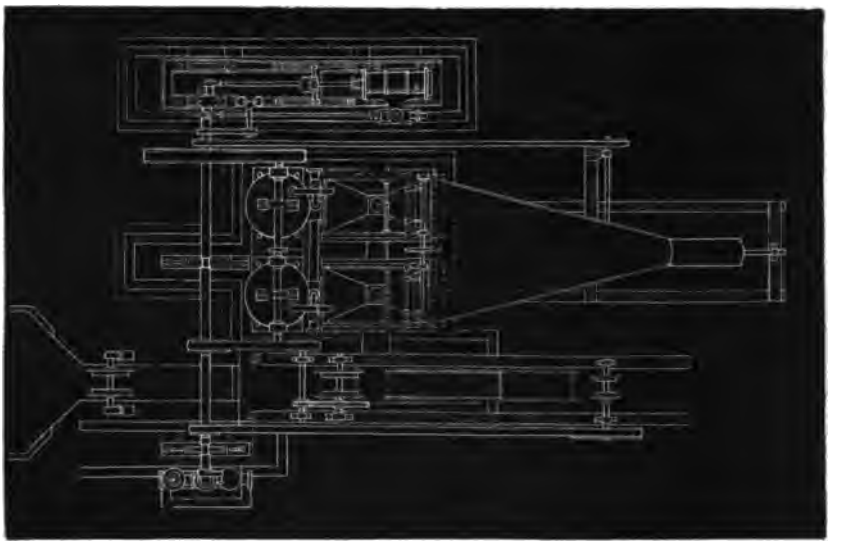
Figs. 56, 57, illustrate the machine constructed and introduced by Messrs. ANDREW BARCLAY & SON of Kilmarnock, who have supplied the sketches and the following description:—The coal to be washed is brought in waggons and emptied into a space cut in the ground, from which it is elevated by buckets and guided by shoots to the washing-cisterns. These cisterns are square boxes with a perforated shelf near the centre, on which the coal lies;

FIG. 56.



the washing is accomplished by the water being kept constantly surging through the perforated plate by the action of a piston in the agitating-cylinders. The washed coal, which is the lighter body, is floated over the end of the cistern, assisted by a fan-shaped kicker, into the shoot, and runs down to the screen; the fine coal, passing through the screen, is conducted by a shoot to the waggon placed there to receive it; and the larger lumps, or nuts, fall out at the end of the screen into a shoot, and thence to the waggon. As the coal is the lighter body and the dirt the heavier body, it follows that the dirt must fall to the bottom of the washing-cistern. To

FIG. 57.



allow this dirt to be separated from the coal, there is a valve in the perforated plate opening downwards. When this valve is opened, the dirt

FIG. 58.

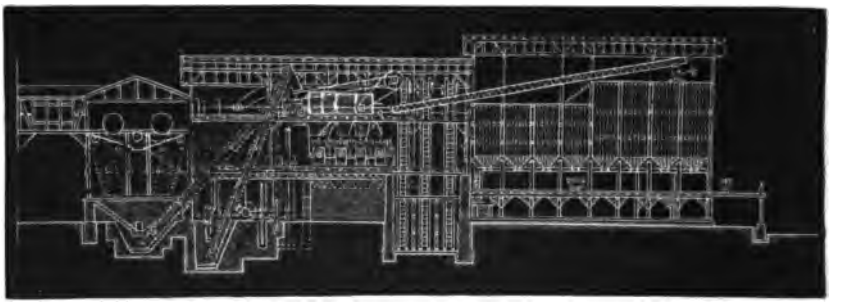
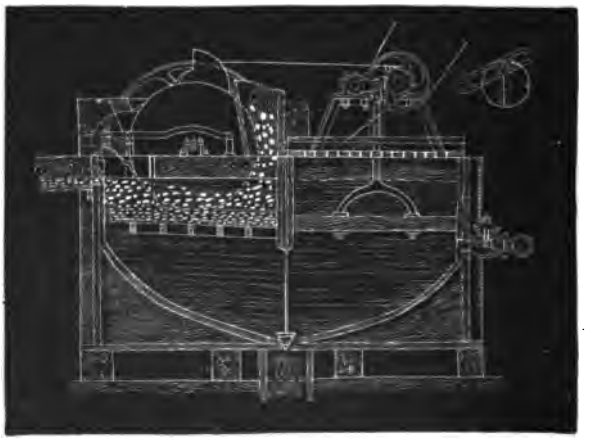


FIG. 59.



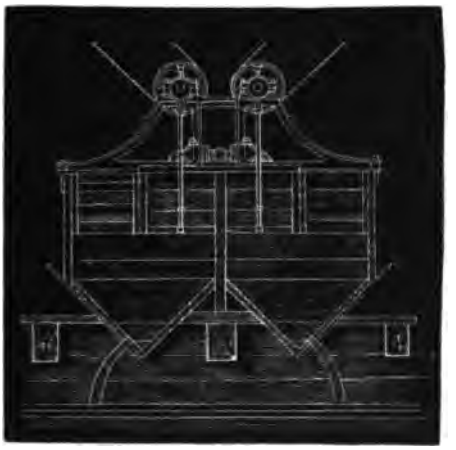
lying on the perforated plate is allowed to drop into the chamber below the perforated shelf; from thence it runs down a pipe to the dirt cistern. From this cistern it is elevated and emptied into a shoot, which conveys it to the waggons placed to receive it.

Each cistern in the machine shown is capable of washing about 60 tons of dross per day of ten hours.

The BOCHUM MINING AND SMELTING COMPANY in Westphalia, in order to obtain a pure coke for their blast furnaces, established in 1878 at one of their collieries a complete set of apparatus for washing the coal on the LÜHRICH system.

Figs. 58, 59, and 60 partly illustrate the plant employed on this system, Fig. 58 being a sectional elevation showing the general arrangement of screens, hoppers, elevators, and washers; Fig. 59 a section of the large coal washer; and Fig. 60 a section of the washer used for small coal.

FIG. 60.



The following description of this plant was given by Mr. F. Baare of Bochum before the Iron and Steel Institute in 1883:—

"The washing plant consists of the following parts:—

"1. The Briart patent screens, by means of which the large coal is separated from the small, the latter only being treated in the washers.

"2. The separating-drum, which divides the coal to be washed into different sizes.

"3. The washers for the coarse or nut coal.

"4. The washers for the fine coal.

"5. The disintegrator for washed nuts.

"6. The arrangements for transporting the washed coal to the store-bunker.

"7. The settling-ponds.

"8. A centrifugal pump for effecting the circulation of the necessary water for the washing process.

"The whole of the machinery is set in motion by a steam-engine of about 140 horse-power. The water used for washing is taken from the pit, and is conducted through a pipe to the centrifugal pump, by which it is raised into an elevated reservoir, together with the returns from the settling-ponds; from the latter, the washers are supplied with the necessary water by means of a system of pipes. The quantity of water supplied through the

centrifugal pump amounts to about 8 cubic metres per minute, of which about a tenth part is fresh pit-water.

"The operation of washing the coal is conducted in the following manner:—The coal, on being raised from the pit, is tipped from the waggons on to two Briart screens, whence all coal of over 69 mm. is passed on to another screen of great length; here it is cleaned by hand-picking, and then conveyed to the railway trucks. All the coal that passes through this screen up to 96 mm. is taken to a separating-drum situated in the upper storey of the building. This divides it into the following five sizes: Size—No. 1, nut coal, from 96 to 45 mm.; No. 2, nut coal, from 45 to 24 mm.; No. 3, nut coal, from 24 to 15 mm.; No. 4, nut coal, from 15 to 10 mm.; No. 5, small coal, under 10 mm.

"To prevent the fine sieves from becoming choked or dirty, an arrangement of pipes is provided at the side for keeping them clear by jets of water.

"The nut coal falls directly from the separating-drum into the washing apparatus adapted to this size, which stands underneath. The small coal before reaching the washers passes to a system of six grading-boxes, constructed after the well-known Rittinger system, where the application of a horizontal stream of water, diminishing in speed towards the last grading-box, sorts the grains of coal according to the time occupied by each in sinking.

"In accordance with the number of grades, there are provided four washers for nuts and six for the smaller sizes of the coal.

"The most important part in both systems is the bed of stone, laid on a perforated bottom, which is formed for the nut-coal washers of coarse pieces of slate, and for the small-coal washers of broken crystalline felspar.

"The washing process consists in the regular rocking motion imparted by the piston to the water, a stream of which is supplied through an opening situated underneath the piston at the back of the apparatus and regulated by a valve. This peculiar motion of the water favours the separation of the particles of slate from the coal, and at the down-stroke of the piston sufficiently raises and opens the bed of slate or of felspar to allow the particles of slate to pass through it and through the perforated bottom into the lower part of the trough, whence they are carried away.

"The washed product of the nut-coal washers, after passing through a system of draining-sieves for the purpose of being freed from water, is conveyed to loading-bunkers discharging into railway trucks, whilst the nut coals which are intended for coking have to undergo a second washing on a large fine-coal washer, and are subsequently, by means of a screw, carried on to the disintegrator. From this, the coal is carried by a bucket apparatus and travelling-belt, and is fed into a larger screw, which conveys the whole of the washed coals that are intended for coking into a store-bunker.

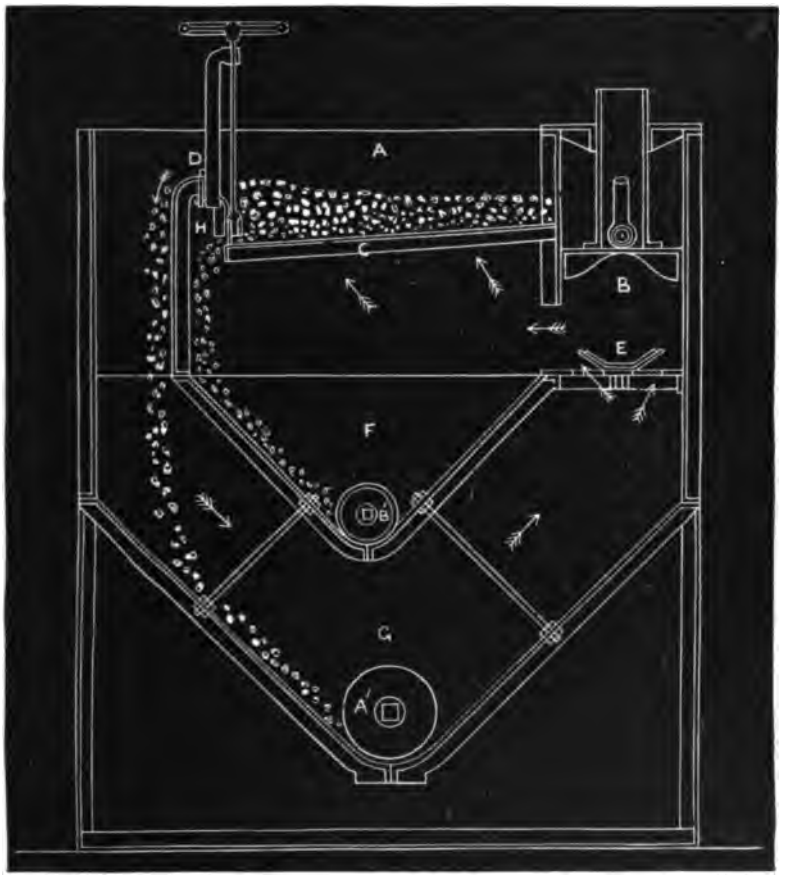
"The produce of the fine-coal washers flows into a large receptacle situated at a low level; from this, by means of a three-bucket apparatus, it is lifted into the large screw mentioned above, the overflow being freed from suspended particles of coal in settling-ponds.

"The slate mud discharged by the washers is also first conveyed into a box narrowed towards the bottom. The coarser parts are lifted by means of a bucket apparatus to be carried off, whilst the overflow, charged with the finest particles, is passed through two separate settling-ponds. The coarse slates which are separated in the nut-coal washers, and through a side opening drop into troughs, are by means of bucket-wheels lifted from these troughs into shoots, which convey them into a separate receptacle, whence they are carried to the waste-heap.

"A point of particular importance for the regular success of the washing process is the thickness of the stone bed lying on the perforated bottom of the washer, and the size and shape of the stones composing it. Experience

proves that only such minerals as have a specific gravity similar to slate are suitable for the stone bed; for the current of water rising through the perforated bottom must have just such a velocity that it holds the slate in suspension, or at the most raises it only a trifle, while the coal, in consequence of its lower specific gravity, is raised considerably. At the same time the stone bed must rise and open readily, so that, on the subsequent receding of the water, the slates, which sink more quickly than the coal, may pass into the interstices of the bed before it settles and closes. The coal, sinking more

Fig. 61.



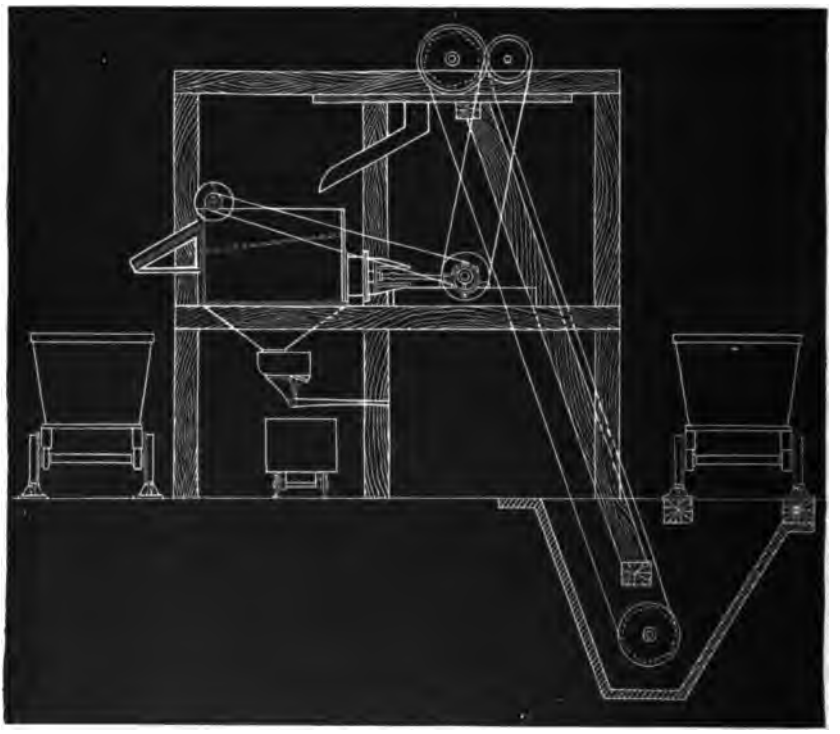
slowly, arrives on the bed only after it is firmly closed, and therefore floats away in the horizontal water-current above. Gradually, as the up and down strokes are repeated, the slates work themselves through the stone bed, and finally pass through the perforated bottom and are carried away.

"Lührich has experimented with a large number of minerals, and has found felspar to be the most suitable material; all its physical properties, such as its crystalline form, laminated fracture, hardness, specific gravity (2.5 to 2.6), answer those conditions under which the separation is most perfect. The pieces of felspar, owing to their flattened shape, arrange themselves so that their larger faces are parallel to the direction of the horizontal water-current, and on the receding of the water retain between their sharp-edged side-faces

the slates entangled in their interstices. After about six weeks' use, the edges of the spar are so much worn and blunted that fresh material has to be put in; the spar of the nut-coal washers, after crushing and sifting, can again be utilized in the fine-coal washers, while the former are supplied with the fresh material. A perfect separation of the slate, which has a sp. gr. of about 2.3, from the coal of a sp. gr. of 1.3 can be effected only if the particles of coal are kept floating and the water continually rising and falling.

"Experience has proved that with the following dimensions a good working of the apparatus will be secured—viz., for the fine-coal washer, length of stroke 3 to 10 mm., strokes per minute 250 to 200; for the nut-coal washer, length of stroke 40 to 80 mm., strokes per minute 70 to 60.

FIG. 62.



"About 1000 tons per day can be worked in the plant described. The washed coal contains 3.6 per cent. of ash."

Mr. H. Simon, of Manchester, who has introduced this system of coal-washing into Britain, states that the arrangement described by Mr. Baare refers only to one installation, and that there are not two exactly alike of the 150 which Mr. Lührich has carried out. This is important, because it cannot be expected that any one washing-apparatus or arrangement can prove perfectly satisfactory for all cases.

At Bochum, the coal before washing contains 8 per cent. of ash, and after washing 3.6 per cent., as stated by Mr. Baare. The coke made from the unwashed coal used to contain 10 per cent., but, since washed coal has been used, it contains only 4.57 per cent. of ash. The cost of washing is in this case less than one halfpenny per ton of coal.

Fig. 61 (p. 135) illustrates the machine made by SHEPPARD of Glamorganshire, which is used in many collieries. It has the advantage of utilizing the same supply of water repeatedly, only that which is absorbed by the coal and dirt having to be made up with a fresh supply. The water circulates in the

FIG. 63.

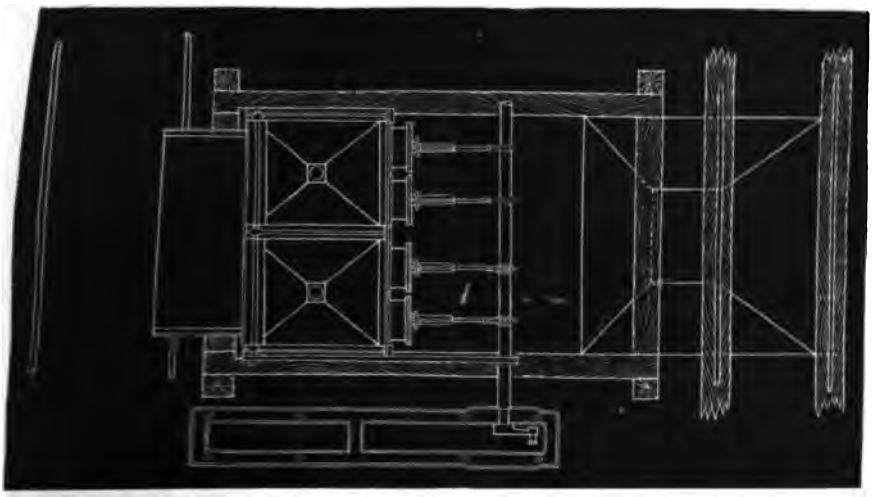
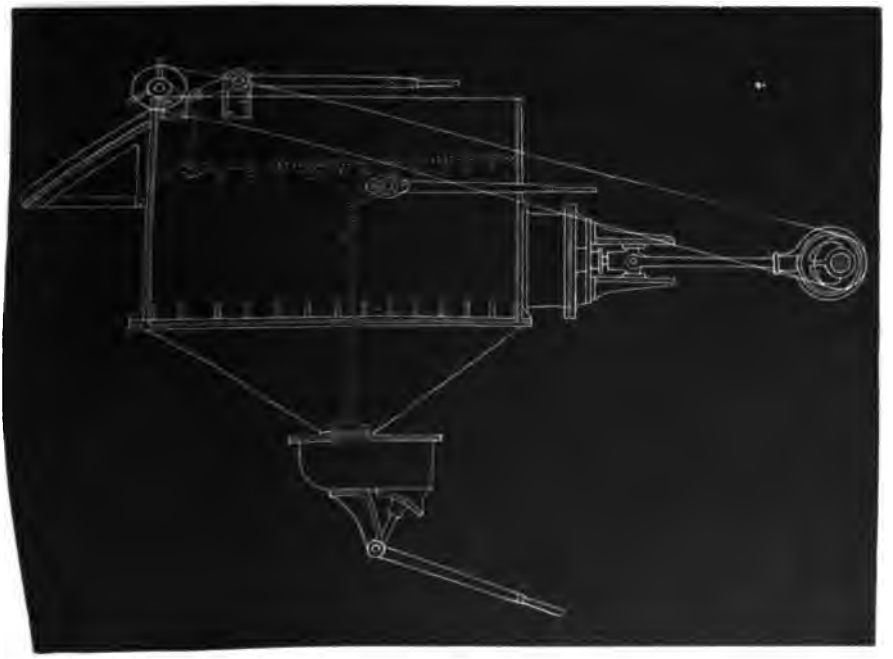


FIG. 64.



washing-chamber of the machine, and consequently the fine coal is not carried away as in some other machines which necessitate the use of settling ponds or chambers.

A suitable arrangement of elevators is combined with the washer for

conveying the coal to be washed from the hopper or receptacle into which it is shot from trucks, and for raising the washed coal and dirt to their respective shoots, which direct them into trucks.

The washer is one of the piston plunger kind, *B* being the piston which

FIG. 65.

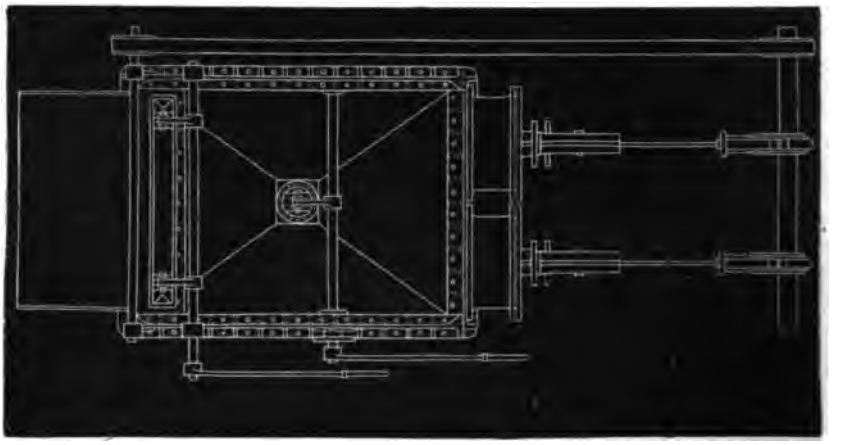
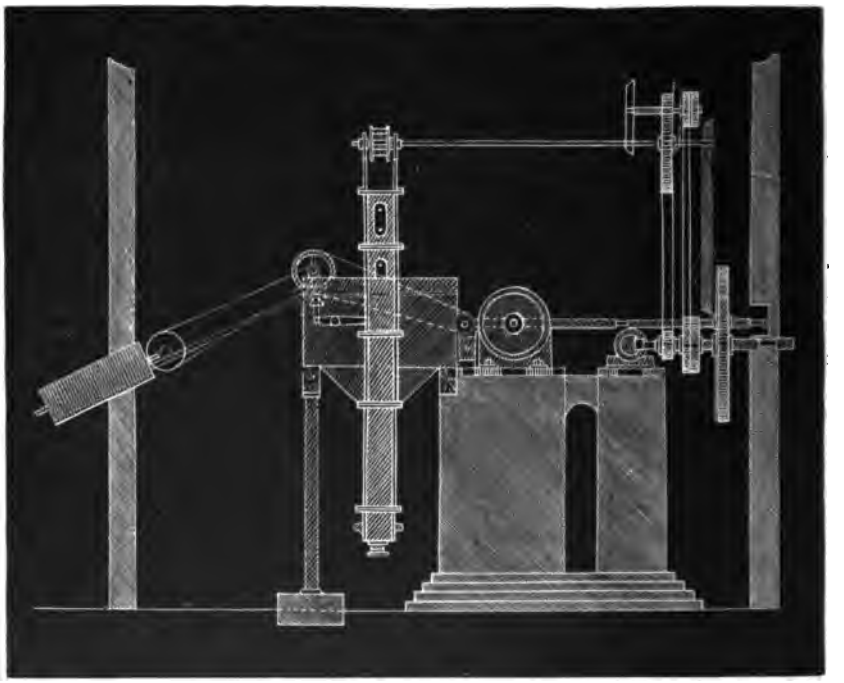


FIG. 66.



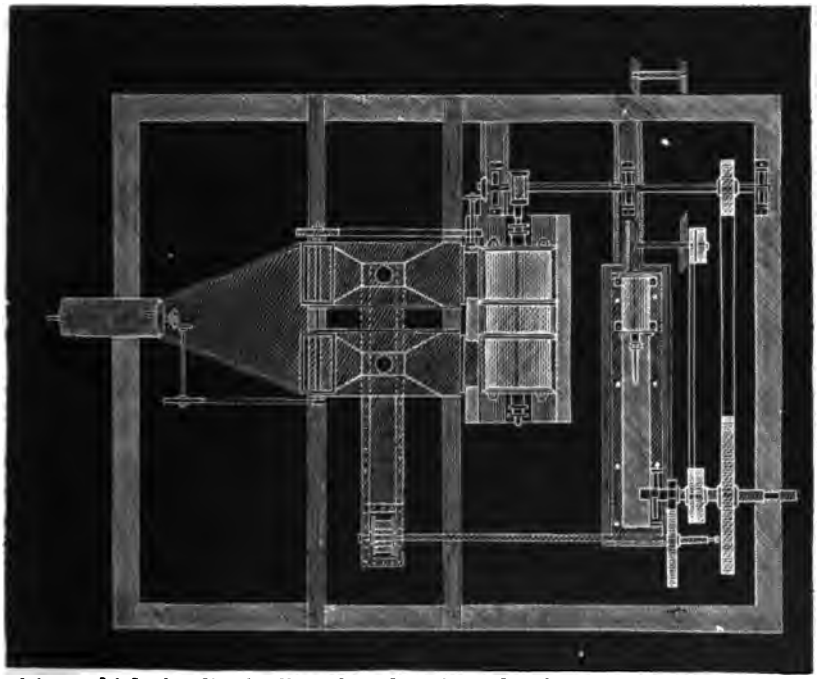
forces the water upwards through the perforated table *C*, upon which the coal to be washed is discharged at *A*. At *D* the water carrying the floating coal passes over a division, and falls down into the lower settling-chamber *G*, the coal passing out by the screw *A'* into the elevator, while the water is drawn by the upward movement of the piston through foot valves at *E*.

The dirt passes away from the coal through an adjustable valve at *H*, and falls into the upper division or chamber *F*, passing out by the screw *B'* to its elevator.

Messrs. GRANT, RITCHIE, & Co. of Kilmarnock make the serviceable machine illustrated in Figs. 62, 63, 64, 65.

It is a piston washing machine, but has the peculiar feature that the cylinders are placed horizontally, the piston-rods being worked by eccentrics off a shaft driven by belting, or off an extension of the engine crank shaft. The water is forced through the usual perforated table upon which the coal lies, and the washed coal is floated over the edge of the cistern at one end assisted by a revolving fan or kicker. It falls on an inclined perforated shoot, and drops into trucks placed beneath. The dirt accumulates on the perforated table under the kicker, and a plug-valve is there arranged, by

FIG. 67.



raising which the dirt is allowed to drop into the chamber below, from which it is periodically removed in trucks through another valve worked, like the former one, by a lever.

A machine designed by Messrs. KERR & MITCHELL, coalmasters, and erected at their Glenclelland Colliery, has also a horizontal cylinder arrangement with some interesting features.

Figs. 66 and 67 illustrate this apparatus, the speciality of which is the arrangement by which agitation of the water is produced. The usual arrangement consists of a vertical cylinder, open at the top, in which a piston or plunger works and forces the water downwards. In Grant & Ritchie's machine, a horizontal cylinder to each box or tank containing water is adopted, the piston acting only on its stroke towards the box. As it is almost impossible to keep pistons water-tight, there is some leakage past the piston, and this necessitates a pipe or outlet for this water from the end of the cylinder farthest from the tank. The piston being single-acting, no more than one

tank or box can be served by one cylinder. In Kerr & Mitchell's machine the position of the cylinder is at right angles to that of Grant, Ritchie, & Co.'s, and water is admitted to both sides of the piston, there being an opening to a box or tank at each end of the cylinder. Thus the piston is doing useful work, when moving in either direction, and it is not necessary to expel any leakage water from the cylinder. This construction also makes it necessary to bore out only one cylinder in fitting up two "boxes" or tanks.

In order to prevent water running with the washed dross into the waggons and so destroying them, Messrs. Kerr & Mitchell have introduced a revolving riddle, which is placed at the end of the shoot from the washing tank or box. One half of its length is formed of $\frac{3}{16}$" mesh, and the remainder of the size of mesh required for good-sized "nuts." The water and washed dross run from the tank down the shoot and fall into the riddle; the water going through the small mesh is carried away by an inclined shoot or channel placed under this portion of the riddle. The very small coal which escapes with the water is subsequently removed from it by an arrangement of revolving wheels with perforated zinc buckets, and the water passes on to the settling-ponds.

Although these machines operate efficiently, yet there are very few in this country which are arranged with the same care as to detail, or so elaborately, as those in Germany, France, and Belgium.

Descriptions of the arrangements in use in these countries will be found in "Engineering," "Iron," "The Engineer," the "Proceedings of the Institution of Civil Engineers," the "Journal of the Iron and Steel Institute," and other technical works.

COKE.

For purposes connected with the arts, coke must be compact, in large pieces not liable to crumble and form dust, and it must possess a certain degree of solidity so as to withstand the pressure in smelting furnaces. Both qualities must be considered in the choice of the material selected for its production. Experience has proved that the softness of coke depends to a very great extent on the process employed in making it, and that it may be rendered more compact by judicious management in the coke-ovens. If, for instance, coke is prepared under considerable superincumbent pressure, the blisters which form in the softened coal are pressed together, after the escape of the gases which caused them, and a denser coke is produced; moreover, long-continued heat tends to render the coke more dense and hard. In order to obtain good coke, caking coal, which approaches sinter coal in composition, should be selected.

In the production of coke from the small coal of the northern coal-field of England, nearly every description of caking coal will make good coke, provided the duff be screened out, in which the whole or nearly all of the shale and mineral matter is found.

Coke, being much less inflammable than charcoal, only burns well with a good draught, and is soon extinguished in kilns with little draught and in the open air. As the coal from which it is produced is always furnished on the same spot, fewer precautionary measures are requisite in preparing it, and the operation of coking may be easily and most economically carried on in a fixed plant.

Produce.—The amount of coke obtained from coal varies with the temperature employed in the manufacture; but, according to Karsten's experiments, the variation is not so great as is observed with charcoal. With wood, nearly double the quantity of charcoal, or 12 per cent. more, was obtained by charring at a low heat; with coal, there is only a gain of 5 or 6 per cent. in coke. More depends here on the quantity of carbon in

the coal, the amount of ash that it yields, and the manner in which the elements, carbon, hydrogen, and oxygen, are combined. In consequence of these numerous conditions which affect the yield of coke, it is extremely difficult, if not impossible, to predict what will be the amount of produce from any given specimen without a direct experiment. The importance of this determination of the amount of coke yielded by any specimen of coal, for its application as fuel in the arts, is so great that vast numbers have been analysed, some of the results of which examination have already been given in the tables at pp. 53–56. We here add a further table, and refer to those at the end of the volume.

The quantity of coke obtained from British coals, as examined by the authors of the Admiralty Report, &c. (see p. 56), averages from 54.22 to 72.60 per cent., the ordinary value being the lower.

The produce of the American bituminous coals, examined by W. R. Johnson, was from 53 to 76.6 per cent., as will be seen in one of the columns of a table below (see Relative Value of Fuel).

The following are the quantities obtained by Karsten from Continental coal, of various districts, distributed according to the usual foreign classification:—

100 Parts of Coal from:		Yield: Coke.	Ash.	Fixed Carbon.
	SAND COAL.			
Upper Silesia	Caroline	65.6	2.8	62.8
	Charlotte	67.5	2.42	65.08
	Beate	66.8	11.9	54.9
	Theodor	53.5	1.9	51.6
	Josepha	56.9	3.4	53.5
Lower Silesia	Laura	70	1.85	68.15
	„	73.5	2.4	71.1
	Fuchsgrube	59.1	2.1	57
Saarbrücken	Geislautern	62.1	3.9	58.2
England	Cannel coal	69.8	13.3	56.5
	Brazils	59.5	1.6	57.9
	„	66.5	28.4	38.1
	SINTER COAL.			
Upper Silesia	Königin Louise	67	1.2	65
	Königsgrube	65.3	0.6	64.7
	Henriette	63.8	1.65	62.15
	Treue Caroline	61.5	4.8	56.7
Lower Silesia	David	68	2	66
	Louise Auguste	66.5	1.3	65.2
	Frischauf	78.8	23.4	55.4
	„	73	8	65
Saarbrücken	Prinz Wilhelm	62.1	1.3	68
	Merchweiler	61.88	0.9	60.98
	Gerhardgrube	58.5	1.6	56.9
Saxony	Planitz (Pechkohle)	64.5	1.1	63.4
	CAKING COAL.			
Upper Silesia	Friedrich zu Zawada	60	2.1	57.9
	Sackgrube zu Ezernitz	58.5	5.8	52.7
	Stollenflötz zu Hultschin	86.9	2.1	84.8
Lower Silesia	Gnade Gottesgrube	66.8	4.65	62.15
	Gustavgrube	69.9	1.9	68
	Glückhilfgrube	68	0.8	67.2
	Kombinirte Abendröthe	75	4.9	70.1
Saarbrücken	Sulzbach Duttweiler	64	0.15	63.85
	Friedrichsthal	64.8	0.65	64.15
	Wellesweiler	65.6	1	64.6

YIELD OF COKE FROM CONTINENTAL COALS—*continued.*

100 Parts of Coal from:		Yield: Coke.	Ash.	Fixed Carbon.
	CAKING COAL—*continued.*			
Saalkreis	Wettin	78	10.8	67.2
	"	81.1	24.4	56.7
	"	77.5	5.1	72.4
Eschweiler	Fornagelflötz	80	1.3	78.7
	Schlemmerichflötz	84.5	3.25	81.25
	Flötz-Gyr	81.5	1.17	80.33
Westphalia	Hütterbank	86.3	1	85.3
	Sälzer und Neuack	82.3	0.7	81.6
	Stock und Scheerenberg	80.1	0.65	79.45
England	Cannel coal	51	0.5	50.5
	"	61.5	5.5	56
	Newcastle	68.5	0.85	67.65
Saxony	Pottschappel (Gute Schicht)	68.7	27.7	41
France	Burg-Lastic	82.9	5.8	77.1
	Anzin	75	3.5	71.5
	Foudary	78.8	7.2	71.5
	Creuzot	68.8	3.4	65.4
	ANTHRACITE SINTER COAL.			
Upper Silesia	Therese zu Hultschin	88.4	2.66	85.74
Saalkreis	Löbejün	89.1	9.1	80
	"	90	20	70
Westphalia	Turteltaube	86.8	2.4	84.4
	Louisen-Erbstollen	72.8	1.4	71.4
	Sperling	85.5	3.5	82
	Hamburg	89.1	0.9	88.2
Belgium	Mons	88	2.5	85.5
	ANTHRACITE SAND COAL.			
Principality of Badenberg	Neu Langenberg	93.6	0.8	92.8
	Hoheneich	94.8	1.2	93.6
	Furth	95	0.7	94.3
	Abgunst	96.4	1.75	94.65
Saalkreis	Löbejün	92	7	85
	"	90	9.9	80.1
Westphalia	Alter Hase	92.5	1.7	90.8
	Hundsnocken	92.8	0.6	92.2
	Schwarzer Junge	91.9	1.1	90.8

If the percentage of coke obtained from the pure organic portion of the coal (that is, the ash deducted) be calculated from the tables above, and compared with the actual quantity of carbon contained in the coal as deduced from former tables, we shall find the following relations:—

	Actual carbon contained in coal per cent.	Coke produceable from coal per cent.
Sand coal	75—80	55—65
Sinter coal	80—85	60—70
Caking coal	85—90	60—80
Anthracite sinter coal / Anthracite sand coal	90—95	85—94

Regnault has shown, however, that the percentage of carbon in the coal is not always a correct indication of the quantity of coke that it will yield, and that greater differences in coke-produce, even than those stated above, occur in some varieties of coal. It is proved, therefore, both by theory and

experiment, that no certain amount of coke-produce can be obtained from a coal of a known percentage of carbon; the only safe criterion, on which every large consumer of coke can base his calculations, must be the mean actually obtained from a large number of coking operations. Still, as will be observed, the amount of coke does, *on the whole*, rise with the actual amount of carbon present in the coal.

The annual average, from observations made at Rive de Gier, was 69 per cent. coke; with inferior coal and less care, not less than 60 to 65 per cent. were obtained; whilst coal and pit-dust in the heap yield only 45 to 50 per cent.; and in the ridges, rich coal yields 40 to 45 per cent. Coal containing little hydrogen produces ⅛ more. General experience has shown that the oven produces denser coke than the heap; and this, again, coke more dense than the ridges; and yet the coals in the two latter cases scarcely yield their own volume, whilst in the ovens this increases in the ratio of 10 : 12. On the other hand, the smelters find the coke from heaps and ridges much more free from sulphur than that made in ovens.

Nature of Coke.—The physical appearance, as also the chemical constitution of coke, varies with the nature of the coal from which it has been prepared and with the mode of its preparation. It is generally a highly porous vesicular mass, varying in colour from a blackish-grey with a more or less fatty lustre, in that prepared from coal rich in oxygen, to a light iron-grey with a fine silky or almost metallic lustre, in that obtained from caking-coal, which has much resemblance in structure with a mass of melted slag or lava. A play of colours is often observed in some varieties of coke, and is indicative of the presence of sulphur, in the form of very thin layers of ferrosoferric sulphide. Good coke should be uniform throughout, without any great admixture of fibre coal or shaly matters; it should be dense and compact. Coke, like charcoal, attracts moisture from the air, often as much as 30 per cent., and it is said—but probably on very inadequate authority—to possess greater heating power after having been kept for some time. Too much exposure to the weather renders it soft and liable to crumble. The amount of ash depends, of course, on the amount contained in the coal, and is greater, the smaller the proportion of coke obtained.

The following selection of analyses will give some idea of the composition of the different cokes used in this country:—

	1.	2.	3.	4.	5.	6.	7.	8.	9.	10.
Carbon .	95.51	85.85	90.53	94 21	93.41	93.05	89.87	84.82	96.42	97.60
Ash . .	2.85	12.07	8.46	5.10	5.80	5.37	8.35	14.40	2.75	1.55
Sulphur .	1.64	2.08	1.01	0.69	0.79	1.58	1.78	0.78	0.83	0.85
	100.00	100.00	100.00	100.00	100.00	100.00	100.00	100.00	100.00	100.00

	11.	12.	13.	14.	15.	16.	17.	18.	19.	
Carbon .	94.08	92.44	89 69	91.16	93.54	91.49	94.31	94.67	92.70	
Ash . .	5.04	6.00	8.35	7.65	5.70	7.05	4.97	4.26	5.70	
Sulphur .	0.88	1.56	1.96	1.19	0.76	1.46	0.72	1.07	1.60	
	100.00	100.00	100.00	100.00	100.00	100.00	100.00	100.00	100.00	

Storer and Lewis find that air-dried coke contains occluded gases, in the proportion of about 0.7 c.c. per gram; the gases consisting of 50 to 60 per cent. of carbonic acid, and 2 to 6 per cent. of oxygen. The percentage of carbonic acid increases on keeping.

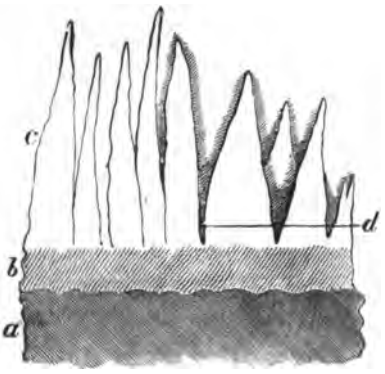
In smelting operations, it is of great importance that the coke should be

hard burnt, so as to be dense and capable of resisting the action of the blast, and also, as pointed out by Sir I. Lowthian Bell, the solvent action of the carbonic acid which passes up through the furnace from the tuyère region, so that solid coke may come down to the tuyères in order to produce the requisite temperature there. Coke of this quality carries twice the burden of ore, and produces—in iron-smelting, for example—a metal of a very superior quality. The nature of the ash is, however, of less importance in smelting than in the locomotive, where the quantity is not so serious an objection, provided it does not scar, so as to obstruct the draught; hence some cokes, which contain a large percentage of white ash, as No. 2, are preferred to those which have a much smaller quantity of ash, but of a kind which melts on the grate-bars.

Great importance is attached to the bright, silvery, metallic appearance of the coke; and some experiments were made three or four years ago to improve this property, by dissolving common salt in the water with which the coal was moistened, but without effect.

The preparation of coke is a very extensive trade in this country, in consequence of the increasing demand for it; and the small of coking-coal, which was formerly of comparatively little value, has, in consequence of its peculiar adaptation to the production of coke, become a most important source of profit. So superior, indeed, is the coke made from small coal, both in density and strength, that it is usual now to grind or partially grind the coal for coking, and washing is always resorted to also where the coal contains a notable proportion of shaly or other mineral matter. There is some difference as respects the management of different qualities of coal in converting them into coke. The great object of the coke-maker is to produce a dense, compact coke, in such large masses that in cases of long carriage, either by sea or land, these lumps may arrive at their destination without being broken up into such small pieces as to be unfit for use. This object is most effectually accomplished by burning large quantities of coal of sufficient depth to ensure long upright masses of coke in the oven at the end of the operation. But some coals, which contain a large percentage of ash, form a coke which melts easily, and when the ovens are charged with too deep a load of such coal, the coke melts, and covers the upper layers in such a manner that the air cannot penetrate to the unburnt coal at the bottom of the oven, and the produce is a mixture of charred coal and coke. On the other hand, when coal contains a large proportion of ash, which does not melt in coking, the same result is observed. This arises, however, from a different cause; the mass of coke at the top which is first formed continues to burn, leaving its ash on the surface, and, this accumulating, at length falls down into the crevices, and chokes the fire before it has time to reach the bottom layer of coal; thus, in Fig. 68, *a* is the unburnt coal, *b* that partially coked, *c* the coke already formed, and *d* the ashes which have fallen down, and prevented the access of air to support the combustion. In such cases, the difficulty in the coking process is obviated by building smaller ovens, and loading them lightly, or by coking by means of external heat applied to the ovens, as in the Appolt or Coppée forms of oven.

Fig. 68.



When suitable coal exists, the advantages of heavy loading are very obvious. The whole mass of coke is longer exposed to the hardening effect of the fire, and the heavy products of distillation, ascending from the bottom layers of coal, deposit large portions of their carbon on the side of the already formed coke, thus increasing the produce from a given quantity of coal. The ovens about to be described are now generally constructed to contain from 7 to 10 tons of coal, and produce a most superior coke, both as respects quality and quantity.

After the oven has ceased to burn, the whole is made perfectly close, and the coke, kept in the heated state for some time, contracts in bulk, and becomes much harder and more compact. In coke intended for iron and other smelting operations, where it is exposed to the action of a blast, long before it really does any efficient duty, the above qualities are most valuable.

The Porosity and Specific Gravity of Coke.—In all metallurgical operations which do not depend on the production of a flame for their efficiency, coke is acknowledged to be the best fuel known; it therefore becomes desirable to ascertain on what its superiority depends. The principal operation for which it is used is the production of pig iron in the blast furnace, and this section will be chiefly devoted to the consideration of the characteristics and advantages of coke as a blast-furnace fuel.

Apart from its chemical composition, the prime requisites of such a metallurgical fuel are that it should enter into combustion with facility at the proper time and in the proper locality within the furnace, so as to produce the requisite temperature; moreover, it should be physically strong enough to withstand the mechanical strain to which it is subjected during its descent with the charge in the furnace. These two characters are of equal importance, and neither can be sacrificed for the other, as is well illustrated by the three fuels charcoal, coke, and anthracite.

Taking the best examples of each kind, the three fuels charcoal, coke, and anthracite form a series in which the first, charcoal, readily enters into combustion and furnishes the proper temperature, but it cannot withstand the mechanical effects of the charge in more than a moderately high furnace, so that, were it not for its freedom from ash and consequently its yielding an iron of exceptional purity, it would scarcely be used for the manufacture of iron except in regions remote from other fuels. The last, anthracite, is well able to withstand the mechanical effects of the charge in the highest of furnaces, but its rate of combustion is slow, and therefore it does not readily give the necessary temperature. The middle member of the series, coke, combines the good qualities of both the others, while the injurious qualities are reduced to a minimum in that it ignites with ease before the tuyeres, yielding the proper temperature; at the same time, it is able to withstand the weight of the charge in the highest furnaces.

If we examine the following analyses,

	Water.	Volatile Matter.	Fixed Carbon.	Ash.
The average of 14 analyses of Swedish charcoal .	5.48	6.72	86.46	1.12
„ „ 2 „ Pennsylvania coke .	0.52	0.436	89.11	9.58
„ „ 30 „ „ anthracites	3.39	3.81	83.79	8.42

we shall see that the principal chemical difference between the charcoal and anthracite lies in the smaller percentage of ash in the former, which gives it a great advantage in the purity of the product manufactured by its use, while the coke possesses a higher content of the most valuable fuel constituent, fixed carbon, and is also higher in ash than either of the others.

With the exception of the ash, the differences in composition of the three fuels are small, and small as they are they are still further reduced in the hot upper portions of the stack by the loss of their water and volatile matter, so that, when the three fuels reach the region of the tuyères, the only chemical difference between them is the difference in the amount of ash they then contain; we are forced to the conclusion, therefore, that the great differences in the use and the results obtained by the three fuels cannot depend on the slight differences in their chemical composition.

If we examine the physical structure of the three fuels, we shall find very great and marked differences, and on these differences depends almost entirely the superiority of coke.

As described by Svedelius: "Properly made charcoal retains distinctly the texture of the wood from which it is made, although its colour is black and it has a glossy fracture, it floats upon water, it will sustain quite a heavy weight if gently laid upon it, but breaks easily by a light quick blow," and "by boiling ordinary good charcoal in water, we may increase its moisture to a very considerable extent." Although it is so soft and friable that it can scarcely come into contact with any other body even very gently without leaving a black mark, yet when sharply struck with a hard body it emits a feebly ringing sound.

The ease with which charcoal enters into combustion is well known, and depends partly on its softness, and partly on its porous nature, as shown by its ready absorption of water. This ease of combustion is one of its chief advantages in smelting iron, but at the same time it places a limit to its use, in that its friable nature and the facility with which it breaks when struck quickly would cause it to be crushed to powder and carried away by the ascending current of gases in the form of dust, long before it could reach the region of the tuyères, if used in furnaces of large size and output, and even if it were not thus crushed it would tend to enter into combustion before reaching the region of the tuyères in such large furnaces, and thus produce abnormal results by the undue heating of the upper portions of the stack; its use, therefore, is confined to furnaces of small size and output, 55 feet being the maximum height and 60 tons a day the maximum output, although the average is very much smaller than this.

Anthracite is of a hard, dense, non-porous structure, and of sufficient strength to bear the burden of the largest furnaces; its denseness, however, is a great drawback to its rapid combustion at the tuyères, as it offers but a limited surface for the hot oxygen of the blast to act on, and at the same time, carbon being a non-conductor for heat, the inner portions of the pieces are only slowly heated by the ascending current of hot gases during the descent of the charge within the furnace; consequently, in order to bring the temperature of the coal to the proper point for active combustion much valuable heat is absorbed in front of the tuyères just where it is most needed to perform useful work. It is claimed by some that the tendency of anthracite to decrepitate, when heated, makes up in a measure for its denseness, by breaking it up into small pieces, which offer more surface for the blast to act on, and are also more readily heated, on account of their smaller size, by the ascending current of hot gases, both these conditions aiding its rapid combustion at the tuyères; on the other hand, it is thought by some that this tendency to decrepitate is injurious rather than beneficial, as it produces dust and thus clogs the flues and gas ways; be that as it may, anthracite is still far from being the equal of coke, the maximum output accomplished by its use being 90 tons per day.

When we examine a piece of coke of good quality, we find that it has a bright, silvery lustre, that it is hard and does not readily yield to pressure,

that when sharply struck it gives a clear ringing sound, but above all we are impressed by its open and porous nature, we see that it is permeated by the ramifications of a complicated and extensive system of inter-opening pores. It is this porous structure which gives coke its great advantage as a metallurgical fuel, and is its prime requisite, so that, in a general way, the more porous a coke is the better it is; but there is a limit to its porosity, and that is the strength of the pore walls, for when the porosity is developed to such an extent that the walls are rendered so weak by their distention that they can no longer bear the burden within the furnace, but begin to crush, then the porosity has reached its maximum beneficial development, and any further increase is injurious rather than beneficial.

This limit to the porosity will of course vary with different coals, and in some cases may be overstepped, although the actual percentage of pores is small, while in other cases it is not reached until the percentage of pores becomes very large. Where this limit to the porosity is passed in the ordinary working, it becomes necessary, in order to produce a sufficiently strong coke, to change the course of the operation in order to arrest or modify the development of the porous structure. This is well illustrated in some recent experiments at Trzymetz in Silesia, where a coal, which under ordinary circumstances refused to coke at all in the Gobeit ovens, was made to yield a coke of fair quality by being crushed and then submitted to hydraulic pressure before being introduced into the ovens.

The effect of this porosity within the furnace is very easily explained. As the charge descends within the furnace, little or no resistance is offered to the free entry of the hot gases of the ascending currents into the body of each piece of the coke, so that they soon become thoroughly permeated to their very centres with these hot gases, which readily impart a portion of their surplus heat to the coke, and this becomes hotter and hotter until, finally, when it reaches the very hot air of the blast in front of the tuyères it has already acquired such a temperature throughout that its combustion is very much aided. At the same time, it offers such an enormous surface for the hot oxygen of the blast to act on that it enters into combustion very rapidly indeed, and thus furnishes the high degree of temperature necessary for the rapid and successful working of the furnace.

Notwithstanding the ease, therefore, with which the coke enters into combustion when properly prepared by this preheating, its carbon is very hard and dense, and does not ignite readily or at all in the cooler upper portion of the blast furnace, thus avoiding the derangement of the furnace by the undue heating of these upper parts.

In the application of coke to the smelting of iron, the maximum height of furnace employed is 90 feet, but the most productive furnaces are somewhat shorter than this. The "D" furnace of the Edgar Thompson Steel Co. at Bessemer Station, Alleghany Co., Pennsylvania, measures 80′ by 20′, and has reached the enormous output of 299 tons of 2268 lbs. in twenty-four hours; while this, of course, is excessive and very unusual, it has averaged over 230 tons of 2268 lbs. per day for a month at a time. There are many coke furnaces measuring from 60′ to 80′ by from 16′ to 20′ which average from 125 to 150 tons per day.

That the rapid and economical working of a furnace is largely dependent on the facility with which the fuel burns is indirectly, but on that account all the more clearly, indicated by the great change which has taken place in the ideas of furnacemen during the last few years in regard to the method of running the blowing engines of the furnace. It was formerly held that the chief condition of the blast outside of its temperature was the pressure under which it entered the furnace, but now the chief condition is regarded as being the revolutions of the engine per minute, or rather the quantity of

air which is going into the furnace, the more revolutions or the more air going into the furnace the larger the output, the other conditions remaining favourable. In other words, this means that the faster the fuel can combine with the oxygen of the air in front of the tuyères, thus allowing a larger amount of air to be driven into the furnace within a given time, the greater the output will be, the other conditions remaining favourable.

The above remarks are based on the consideration of the best typical examples of each class of fuel. When we consider the different qualities of each fuel, it will, of course, be found that poor grades of coke fail to accomplish as much as the better grades of the other fuels.

The method of manufacturing coke is very crude and wasteful, and there has been very little real improvement in it for many years, although there have been many attempts to introduce new and improved methods, and especially in the direction of means for saving and utilizing the bye-products which are now allowed to go to waste. This failure is due to two causes—first, the lack of exact information as to the true nature and characteristics of a good coke and the behaviour of different coals under varying conditions of manufacture; and, second, the perverse conservatism, not to say prejudice, of furnace managers, who refuse to give a coke, differing in outward appearance or in the method of its manufacture from what they are used to, a fair and impartial trial in their furnaces

As at present understood, and in the present mode of manufacture, the essential characteristics of a good coking coal are that it shall contain not less than 20 nor more than 30 per cent. of volatile hydrocarbons and not too much ash; that on being heated it must pass through a thoroughly fused or pasty condition; and that when in this condition it must part with its volatile matter in such a manner as to form innumerable small pores. If a coal contains less than 20 per cent. of volatile matter it will not fuse properly, whilst if it has more than 30 per cent. the porous structure will be unduly developed at the expense of the strength of the pore walls; on the other hand, many coals lying between these limits will not fuse at all, and therefore do not coke, while others fuse properly but give off their gas so as to form large and thin-walled pores. A coal occurring at Soddy, Hamilton Co., Tennessee, containing 27.8 per cent. of volatile matter expanded so much in coking that it ruptured the ovens as at first constructed.

The ordinary methods of making chemical analyses of coal are very unsatisfactory, inasmuch as they fail to show anything whatever of the manner in which the elements are combined, whilst the ordinary statement of an analysis is extremely vague, so that there is great room for improvement in this direction, and improved methods of analysis will undoubtedly open the way to a better understanding of the coking process and facilitate improvements in the methods of coking. The coking takes place in ovens of the typical beehive pattern, of varying size, but mostly of less than 6 or 7 tons capacity, and is accomplished by the combustion of a portion of the coal itself as well as the volatile matters given off during the operation within the oven. It is very essential that there should be no hindrance to the ready escape of the volatile matters, and one of the prime causes of the failure of many of the attempts to save and utilize these volatile matters is the fact that they do unquestionably interfere with the easy expulsion of the volatile material of the coal. This necessity for a free evolution of gas has also limited the size of the beehive oven, as well as interfered with the use of other styles of oven. As soon as pressure within, developed either by an obstruction to the escape of the gases or the weight of the upper portion of a high or deep charge upon the lower portion of the charge, is brought to bear upon the coal in its fused condition it is compressed, and the resulting

coke is dense and not porous. This is to be seen plainly in the coke made in the old style Coppée oven, where the upper layers are much more open and porous than the lower ones, which not only had to bear the burden of the upper layers of material, but were also subjected to a stronger gas pressure.

Whilst this condition of the free evolution of gases is undoubtedly necessary in the treatment of coals which produce a first-class coke in the beehive oven, yet it may well be that a suitable pressure applied to the beforementioned Soddy coal at the proper time might greatly improve the quality of the coke produced by lessening the size of the pores, and consequently increasing the thickness and strength of the pore walls; and the same may be true of other coals which produce an inferior coke in the beehive oven.

The practical method employed by furnace-men and others to determine the relative value of two cokes is to judge by the eye as to the relative porosity, and, if found satisfactory, then to take two pieces of about the same size, each having an approximately flat surface, and rub them together violently for a few moments; the one which appears to suffer the least by this treatment is pronounced the best coke. This, of course, is a very crude and unsatisfactory way of testing, as almost everything depends on the judgment of the tester, which may or may not be influenced by other considerations; it shows, however, an appreciation of the two essential characteristics of a good coke, and has had a value, notwithstanding a more accurate and refined method of testing was very much needed.

When the physical characters of coke shall have been fully and carefully determined, and the behaviour of coking coals under varying conditions thoroughly investigated, so that there is some basis of scientific fact upon which to found new and improved methods of coking, there will be far more probability of success rewarding the efforts of those who are working to that end. Mr. Dewey has made a beginning in this direction by determining the porosity and specific gravity of a series of American cokes, which, however, is not yet completed, but is being carried on as rapidly as possible in connection with other investigations of coke and coal.

In determining the porosity or space occupied by pores in any given body there are two methods which have been used, mostly in the investigation of rocks and principally those that have been used for building purposes. The older and more generally used method is to cut an accurate cube, generally a cubic inch, of the material, dry it thoroughly, weigh, fill its pores with water and weigh again; by a simple calculation the excess of the second weight over the first will give the volume of pores in a cubic inch of the material.

The great objection to this method is the time, care, and attention necessary in cutting an accurate cube, and in the case of coke, owing to its very porous nature, the difficulties are greatly increased. A far easier, neater, and in every way better method, and one that at the same time yields good results, is that proposed and used by Sterry Hunt in the Report of the Geological Survey of Canada, 1863–6, pp. 281–3.

This method is to select suitable specimens of any size or shape, generally between 20 and 40 grams in weight, dry and weigh them, then fill their pores with water and weigh in water; the pieces are then taken out of the water, the excess of water upon their surfaces carefully removed, and weighed again in air. These three weighings furnish all the data necessary for calculating:—

I. The apparent specific gravity, or the relationship between the whole mass of material and an equal volume of water.

II. The true specific gravity, or specific gravity of the particles.

III. The volume of pores in 100 volumes of material, or percentage of pores by volume.

IV. The volume of pores in a given weight of material, as c.c. in 100 grams.

The loss in weight of the material saturated with water when weighed in water, being equal to the volume of water displaced by the mass, enables us to determine the specific gravity of the latter; while this loss in weight, less the weight of the water absorbed by the mass, gives the true volume of water displaced by its particles, and hence the means of determining their specific gravity.

The division of the amount of water absorbed, by the amount of water displaced, gives the amount by volume of the pores in a unit of the material, and the division of the weight of the water absorbed, by the weight of the dry mass, gives the volume of pores in a unit of weight of the material; let

a = the weight of the dry material.
b = the weight of water which the material can absorb.
c = the loss in weight, in water, of the saturated material.

Then—

$c : a :: 1000 : x$ = the apparent specific gravity, or the specific gravity of the mass.

$c - b : a :: 1000 : x$ = true specific gravity, or specific gravity of the particles, water being 1000.

$c : b :: 100 : x$ = percentage by volume of the pores in the material.

$a : b :: 100 : x$ = volume of pores in 100 parts by weight of the material, say c.c. in 100 grams.

In experimenting with coke, it was found necessary to make several changes in the usual proceedings on account of the nature of the material, and the method adopted was as follows :—

Suitable specimens from 20 to 40 grams in weight were selected to represent the average physical condition of the coke. They were thoroughly brushed to remove any loosely adhering particles which might fall off during the experiments, and thus vitiate the results, and were weighed just as they were received; they were dried at a temperature of 100° C. for one hour, cooled under the desiccator and weighed, the loss in weight representing the amount of moisture found in the specimen as received.

Great difficulty was experienced in thoroughly filling the pores with water, on account of the small amount of adhesion between the surface of the coke and the water, but, after considerable experimenting, the following general plan was adopted, which was modified in its details to suit particular cases.

In filling porous substances generally with water, two methods are in use—one to soak the specimens in water for a time and then to place them in water under the receiver of an air-pump and exhaust until no more air is given off; and the other to keep them suspended in boiling water until the pores are filled with water, as is shown by their ceasing to gain in weight on taking them out, cooling, and weighing. In this case, it was found more expedient to use a combination of these two methods. The specimens were placed in water and allowed to remain from twelve to twenty-four hours; they were then placed under the receiver of an air-pump and the air exhausted, the exhaustion being repeated from three to five times. The specimens were then removed and placed in boiling water and boiled for three hours. After becoming nearly cold they were again placed under the receiver of the air-pump and exhausted, and the exhaustion repeated at intervals of ten to twenty minutes, until no more bubbles were seen to come

off; as a precaution, they were further exhausted from six to eight times to insure the removal of the air as completely as possible. Owing to the nature of the case, it is not possible to replace the very last traces of air by water, and, in order to determine the probable error from this cause, eighteen specimens were again subjected to a varying number of exhaustions, amounting in one case to twenty, and it was found that the average gain in weight represented only 0.34 per cent. of the true volume of the coke experimented with, an error sufficient to cause but a very slight difference in the results.

The specimens, now thoroughly saturated with water, were weighed first in water and then in air. The directions laid down by Dr. Sterry Hunt, and the plan generally followed in determinations of porosity, to dry the surface of the saturated specimens with bibulous paper or some other absorbent of water before weighing in air, could not be followed in this case, for, owing to the large percentage of pores in the coke, and to the slight adhesion of water to their surfaces, it was found that, on applying any absorbent material, the water would not only be removed from the surface, but withdrawn from the pores themselves. It was therefore decided that the most feasible plan would be to remove the specimens from the water and allow as much water as would to drain off; they were then weighed as rapidly as possible. Although in this way a double error is induced—first, a plus error from the thin film of water adhering to the surface of the coke, and, secondly, a minus error from the water flowing out of the pores opening upon the surface, these errors will, in a measure, balance each other. It is necessary to take this last weight as quickly as possible, for the evaporation from the surface of the coke is very rapid, and it takes but a few moments for a specimen to lose 10 mg.—in fact, during the time necessary to change the rider on the balance a specimen will sometimes lose as much as 5 mg. In order to determine the probable error of weighing these wet specimens, thirty-three specimens were weighed and again immersed in water, and after standing twelve hours were taken out and weighed again. Of these thirty-three specimens, twenty-five gained weight and eight lost, the average gain being 0.14 per cent. of the total volume of the coke, and the average loss was 0.1 per cent.

In the determination of the specific gravity, there are two sources of variation, one inherent in all specific gravity determinations and unavoidable, and the other accidental and in a measure disappearing in the averages. The first error is due to the possible presence of water-tight pores, or cells, causing a minus error in the determination. The other error is due to the possible presence in a piece of coke of a small piece of slate, causing a plus error. The first or minus error applies also to the porosity determination, but its effect is far less in that case than it is on the specific gravity determination, for in the first case the result is only affected by the actual volume of the water-tight cells, whilst in the second case, apart from this, the determination is affected by the buoyancy imparted to the specimen by the inclosed air or other gas.

The crude and varying conditions under which coke is made naturally tend to produce material of varying characters and qualities, so that among the many needed improvements may be mentioned the production of coke of uniform characters and qualities. For improvements in this direction, so far, reliance has been placed on the experience of the workmen gained from long use of the same coal. Under the most favourable conditions, no one piece of coke can be said to represent one charge of the oven, and much less can it represent the general run of the oven or a set of ovens. In experimenting, it is desirable to select as many

pieces as possible to represent any particular coke; Mr. Dewey usually takes twelve. Differences amounting to 0.236 in the apparent specific gravity, 14.88 per cent. in the percentages by volume of cells, and 33.81 c.c. in the c.c. of cells in 100 grams of coke have been found in the product of the ovens of J. F. Dravo at Connellsville, Pennsylvania, where special efforts have been made to secure uniformity of product.

In carrying out this investigation, 153 specimens of coke were examined, representing eleven localities producing metallurgical coke, and one gas-works coke; in all cases but one, twelve specimens were selected to represent the locality; the exception, Connellsville, was represented by twenty-one specimens. The results given are reduced to the temperature of the maximum density of water (4° C.), and embrace the maximum and minimum determinations in each set, and also the average of the twelve determinations of the following points:—Moisture; true specific gravity, or the actual specific gravity of the coke; apparent specific gravity, or the relationship between the whole volume (including the coke and the cells) and an equal volume of water; the percentage of cells by volume, and the volume of cells in a given weight of coke (cubic centimetres in 100 grams). It must be borne in mind, however, that although the determinations are given in a line for convenience, yet it does not follow in every case that related results are obtained from the same specimens—that is to say, while in some cases the maximum apparent specific gravity and the minimum percentage of cells given are the results obtained from the same specimen, yet it is not always so; for, in following out the relationships between the results, it is necessary that all the determinations of a specimen should be taken into consideration, and in some cases the results obtained from different specimens, in one or more determinations, will agree within the probable error of determination.

The most important and best developed coke region in America is the section of country about Connellsville, Fayette Co., Pennsylvania, and the product of the Connellsville ovens has a very high reputation over the whole country, so much so that there is scarcely an important metallurgical centre to which it has not at some time penetrated, its intrinsic worth being aided in this direction by the very low cost of production.

The ovens, of which about 10,000 are in operation, manufacture coke mainly for sale in the open market, only a small proportion of them being controlled by iron-making concerns who make and use their own coke

The region occupies a small separated basin in which the Big or Pittsburgh seam of coal reaches a remarkable development and a change in character, which renders it more suitable for the manufacture of coke than at any other place in the State. The mining of the coal is very simple and inexpensive, and the details of the manufacture have been so systematized and cheapened that coke is sold at a very low rate at Connellsville.

The oven in use at Connellsville is of the typical beehive pattern, 11 to 12 feet in diameter, and 5½ to 6 feet in height, and has not been materially changed for over half a century. The time occupied in the coking operation is usually forty-eight hours, or two days, while seventy-two hours, or three days, are allowed for the charges that would otherwise be drawn on Sunday. Occasionally twenty-four hour, or one day, coke is made. The seventy-two hour coke is regarded as being much the best.

The chemical composition of the coal and coke is represented by the following analyses:—

COAL.

	Broadford.		
	Lump.	Slack.	
Water	1.260	0.950	—
Volatile matter	30.107	29.662	31.36
Fixed carbon	59.616	55.901	59.62
Sulphur	0.784	1.931	0.784
Ash	8.233	11.556	8.23
Total	100.000	100.000	99.994
Colour of ash	Reddish grey	Reddish grey	—
Coke, per cent.	68.633	69.388	—
Analyst	A. S. McCreath	A. S. McCreath.	T. T. Morrell

COKE.

	Broadford.	J. F. Dravo.	J. F. Dravo.		
Water	0.030	0.040	0.110	—	—
Volatile matter	0.460	0.352	0.471	—	—
Fixed carbon	89.576	88.906	88.403	87.46	87.26
Sulphur	0.821	0.771	0.838	0.69	0.746
Ash	9.113	9.931	10.178	11.32	11.99
Total	100.000	100.000	100.000	—	—
Analyst	A. S. McCreath	A.S.McC.	A.S.McC.	—	—

To represent this region twenty-one specimens were selected.

A series of nine specimens from the Broadford Works of Frick & Co., taken from a shipment to the Crozer Furnace at Roanoke, Virginia, yielded the following results:—

COKE.—CONNELLSVILLE, BROADFORD—FRICK AND CO.

	Moisture.	True Specific Gravity.	Apparent Specific Gravity.	Per Cent. of Cells by Volume.	c.c. in 100 Grams.
Maximum	0.096	1.79	1.033	54.37	66.31
Minimum	0.008	1.73	0.819	42.20	40.83
Average	0.034	1.76	0.892	49.37	55.73

A series of twelve specimens, three samples being taken from each one of the following works—1, Morrell ovens; 2, H. C. Frick & Co.; 3, Schoonmaker & Co.; 4, J. F. Dravo—yielded the following results:—

NO. 1.—MORRELL OVENS.

Moisture.	True Specific Gravity.	Apparent Specific Gravity.	Per Cent. of Cells by Volume.	c.c. in 100 Grams.
0.020	1.65	0.716	56.61	78.90
0.017	1.80	1.007	44.02	43.69
0.065	1.74	0.990	43.23	43.66

NO. 2 — H. C. FRICK AND CO.

Moisture.	True Specific Gravity.	Apparent Specific Gravity	Per Cent. of Cells by Volume.	c.c. in 100 Grams.
0.011	1.69	1.016	40.04	39.05
0 339	1.69	0 880	47.88	54.39
0.046	1.67	0 873	47.65	54.58

NO. 3.—SCHOONMAKER AND CO.

Moisture.	True Specific Gravity.	Apparent Specific Gravity.	Per Cent. of Cells by Volume.	c.c. in 100 Grams.
0.023	1.83	1.119	38.76	34.62
0.016	1.82	0.900	50.43	56.03
0.023	1.81	1.054	41.94	39.79

NO. 4.—J. F. DRAVO.

Moisture.	True Specific Gravity.	Apparent Specific Gravity.	Per Cent. of Cells by Volume.	c.c. in 100 Grams.
0.012	1.69	0.979	42.33	43.23
0.025	1.78	0.837	52.99	63.27
0.042	1.73	0.743	57.21	77.04

SUMMARY.

	Moisture.	True Specific Gravity.	Apparent Specific Gravity.	Per Cent. of Cells by Volume.	c.c. in 100 Grams.
Maximum .	0.339	1.83	1.119	57.21	78.90
Minimum .	0.011	1.65	0.716	38.76	34.62
Average (12)	0.053	1.74	0.926	46.92	52.35

The general results of the twenty-one specimens are as follows:—

Connellsville Coke.	Moisture.	True Specific Gravity.	Apparent Specific Gravity.	Per Cent. of Cells by Volume.	c.c. in 100 Grams.
Maximum .	0.339	1.83	1.119	57.21	78.90
Minimum .	0.008	1.65	0.716	38.76	34.62
Average (21)	0.045	1.75	0.912	47.97	53.84

A much less developed but rapidly growing coke region is the section of country along the New and Kanawha rivers, in the State of West Virginia, on the line of the Chesapeake and Ohio Railway. Several large iron furnaces have been built on this line of railway, and others depend on the coke of this region. As it becomes better known, it is more highly esteemed, and bids fair to become the rival of the older and better known Connellsville coke. The coals of this region are especially free from ash, and furnish a remarkably pure coke. Iron made by its use has been employed with success where formerly only charcoal pig was used.

The coal of the Middle Measures (XIII. of Rogers' Survey) has been used for making coke in beehive ovens at Eagle and St. Clair, on the Kanawha, for sale in the open market.

Twelve specimens from each of these localities have been examined with the following results:—

COKE.—EAGLE OVENS, WEST VIRGINIA.

	Moisture.	True Specific Gravity.	Apparent Specific Gravity.	Per Cent. of Cells by Volume.	c.c. in 100 Grams.
Maximum .	0.074	1.74	0.979	58.14	86.54
Minimum .	0.006	1.60	0.672	41.39	42.66
Average (12)	0.021	1.68	0.894	46.85	53.89

COKE.—ST. CLAIR OVENS, WEST VIRGINIA.

	Moisture.	True Specific Gravity.	Apparent Specific Gravity.	Per Cent. of Cells by Volume.	c.c. in 100 Grams.
Maximum .	0.070	1.77	1.125	53.91	74.61
Minimum .	0.008	1.57	0.723	36.25	32.21
Average (12)	0.030	1.67	0.924	44.81	50.23

At Quinnimont, Fayette Co., West Virginia, the coal of the Lower Measures (XII. of Rogers' Survey) is mined and coked for use in the furnace located there. The composition of the coal in samples taken from the different headings of the mine, and also of the coke, is as follows:—

	Coal.				Coke.
Water	0.45	0.44	0.38	0.36	—
Fixed carbon . . .	77.97	77.74	74.90	76.89	92.62
Volatile matter . . .	18.99	20.06	20.15	20.76	—
Ash	2.03	1.17	3.21	1.35	7.23
Sulphur	0.56	0.59	1.36	0.64	0.665
Phosphorus	—	—	—	—	0.050
Total . . .	100.00	100.00	100.00	100.00	—

Analyst, Professor Thomas Egleston.

This coke was made in ovens of the beehive pattern, 9 feet 6 inches, 10 feet 6 inches, and 11 feet 6 inches in diameter, and 6 feet high, the charge being 6800 to 8500 pounds, and the time occupied in coking forty-eight hours. The average yield for a year's working was 64.75 per cent. of the coal charged, and the average of six months was 65.25 per cent.; it is used in the Quinnimont Furnace, 60 by 16 feet, and carries a burden of 2.2 pounds to 1 pound of coke.

A series of twelve samples selected from a four car load lot yielded the following results:—

COKE.—QUINNIMONT, NEW RIVER DISTRICT, FAYETTE COUNTY, W. VA.

	Moisture.	True Specific Gravity.	Apparent Specific Gravity.	Per Cent. of Cells by Volume.	c.c. in 100 Grams.
Maximum .	0.076	1.92	0.791	66.98	105.49
Minimum .	0.010	1.77	0.639	55.93	70.75
Average (12)	0.044	1.83	0.713	61.12	

At Sewell, Fayette Co., West Virginia, Lower Measures coal (XII. of Rogers' Survey) is coked for use in the furnaces of the Longdale Iron Co., at Longdale, Alleghany Co., Virginia, 130 miles distant. The composition of the coal and coke is as follows:—

	Coal.		Coke.
Water	1.03	...	—
Volatile matter . . .	21.38	...	—
Fixed carbon	72.32	...	93.00
Ash	5.07	...	6.73
Sulphur	0.20	...	0.27
Total . . .	100.00	...	100.00

Analyst, C. E. Dwight.

This coke was made in beehive ovens 13 feet by 6 feet, the charge being 12,000 pounds and the yield 62 per cent., the time of coking being forty-

eight and seventy-two hours. It is used in the Lucy Selina Furnace of the Longdale Iron Company, 60 feet by 11 feet, carrying a burden of 2.726 pounds to 1 pound of coke.

A series of twelve specimens yielded the following results:—

COKE.—SEWELL, NEW RIVER DISTRICT, FAYETTE CO., W. VIRGINIA.

	Moisture.	True Specific Gravity.	Apparent Specific Gravity.	Per Cent. of Cells by Volume.	c.c. in 100 Grams.
Maximum .	0.033	1.74	0.891	55.79	74.30
Minimum .	0.007	1.06	0.750	46.41	52.08
Average (12)	0.016	1.69	0.703	53.19	67.39

Lower Measures coal (XII. of Rogers' Survey) is coked at Stone Cliff and Fire Creek, Fayette Co., West Virginia, for sale in the open market. At Stone Cliff, the beehive ovens are 11 feet 6 inches by 6 feet, the charge being 9000 pounds for forty-eight hour and 10,000 for seventy-two hour coke.

At Fire Creek, typical beehive ovens are used, and the coal and coke are of the following compositions:—

	Coal.		Coke.		Coke.
Moisture . . .	0.61	...	0.260	...	0.11
Volatile matter . .	22.34	...	0.260	..	0.35
Fixed carbon . .	75.02	...	92.377	..	92.18
Ash	1.47	...	6.750	..	6.68
Sulphur . . .	0.61	...	0.535	...	0.618
Phosphorus . . .	—	...	0.0146	...	0.027
Analyst .	—	...	H. Froehling	...	J. B. Britton

Twelve samples from each of these localities yielded the following results:—

COKE.—STONE CLIFF, NEW RIVER DISTRICT, FAYETTE CO, W. VIRGINIA.

	Moisture.	True Specific Gravity.	Apparent Specific Gravity	Per Cent. of Cells by Volume.	c.c. in 100 Grams.
Maximum .	0.119	1.79	0.962	57.60	77.85
Minimum .	0.039	1.66	0.740	46.20	50.14
Average (12)	0.074	1.74	0.838	51.79	62.30

COKE.—FIRE CREEK, NEW RIVER DISTRICT, FAYETTE CO., W. VIRGINIA.

	Moisture.	True Specific Gravity.	Apparent Specific Gravity.	Per Cent. of Cells by Volume.	c.c. in 100 Grams.
Maximum .	0.161	1.88	0.897	70.10	126.58
Minimum .	0.024	1.78	0.554	49 99	55.74
Average (12)	0.078	1.83	0.820	55.12	69.05

Upper Measures coal is coked at Rockwood, Roane Co., Tennessee, for use in the blast furnaces located there. The coal is of the following composition:—

Water	1.75	...	1.39
Volatile matter	26.62	...	32.59
Fixed carbon	60.11	...	60.75
Ash	11.52	...	5.27
Total	100.00	...	100.00
Sulphur	1.49	...	—
Analyst	F. P. Dewey.	...	M. M. Duncan.

This coke was made in beehive ovens, 11, 12, and 13 feet diameter, and 6 feet high, the charges being 100 bushels and the coking occupying forty-eight hours. It is used in the two furnaces of the Roane Iron Company at Rockwood, 65 by 16 feet and 65 by 14 feet, and carries a burden of 2.29 pounds to 1 pound of coke.

A series of twelve specimens yielded the following results :—

COKE.—ROCKWOOD, TENNESSEE.

	Moisture.	True Specific Gravity.	Apparent Specific Gravity.	Per Cent. of Cells by Volume.	c.c. in 100 Grams.
Maximum .	0.436	1.75	1.075	51.99	61.95
Minimum .	0.031	1.63	0.839	38.72	36.03
Average (12)	0.192	1.69	0.935	44.81	48.55

Coal from the Lower Kittanning Seam of Pennsylvania, which occupies but a small space in Ohio, is coked at Leetonia, Columbiana Co., Ohio, for use in the blast furnaces located there.

The coal seam is about 30 inches thick, the upper 6 inches being non-coking, and used in the furnace in its raw state.

A sample from the bottom bench of the Salem shaft shows the following composition :—

Water	3 00
Volatile matter	31.50
Fixed carbon	62.35
Ash	3.15
Total	100.0
Sulphur	1.40
„ left in coke	0.60
„ of coke	0.92
Specific gravity	1.274

Analysis from Professor Edward Orton.

This coke was made in ovens of the beehive pattern, 12 by 6 feet, occupying seventy-two hours in the coking. It is used in the furnaces of the Cherry Valley Iron Company at Leetonia, 75 feet by 16 feet and 55 feet by 14 feet. In the large furnace, it carries a burden of about 2 pounds to 1 pound of coke.

This coke exhibits very plainly the effect of a high percentage (31.50 per cent.) of volatile matter in the coal, for while all the cokes previously described have had hard and comparatively thick pore walls, in this one the pore walls are very thin and papery, and crush very readily, so that its practical reputation is much lower than other cokes, especially the Connellsville, with which it comes into close competition. It has the advantage, however, of being in close proximity to valuable iron ore deposits.

A series of twelve specimens yielded the following results :—

COKE.—LEETONIA, COLUMBIANA CO., OHIO.

	Moisture.	True Specific Gravity.	Apparent Specific Gravity.	Per Cent. of Cells by Volume.	c.c. in 100 Grams.
Maximum .	0.142	1.55	0.844	52.83	74.06
Minimum .	0.012	1.46	0.706	36.06	42.71
Average (12)	0.047	1.49	0.770	47.59	62.23

In the western portion of the country, the younger coals of the Cretaceous

and Tertiary have been coked with success at various localities, adding very much to the value of mines of all kinds by greatly reducing the cost of fuel for the metallurgical works.

Coal from the Laramie formation, which lies at the boundary between the Cretaceous and Tertiary, is coked at El Moro, Las Aminas Co., Colorado, for use at South Pueblo, Pueblo Co., Colorado. The composition of the coal is represented by the following analyses:—

	Sample across the Seam, leaving out the Stony Parts.		Sample from a Car-load.
Water at 110° C.	0.95	...	1.14
Volatile matter	29.82	...	29.97
Fixed carbon	56.41	...	56.32
Ash	12.82	...	12.57
Total	100.00	...	100.00
Sulphur	0.41		
Specific gravity	1.305		
Analyst	—	...	H. L. Wells

This coke is made in ovens of the beehive pattern, 11 feet 6 inches by 6 feet, the charge being 4.2 tons, the yield 60 to 65 per cent., and the time of coking forty-eight hours.

The amount of ash, as shown by about forty analyses by Mr. Wells, is 18 per cent., and the percentage of silica in the ash 12 per cent., the sulphur is from 0.46 to 0.53 per cent.

The coke is used in the furnace of the Colorado Coal and Iron Company, at South Pueblo, Colorado, 65 feet by 15 feet, carrying a burden of 2 pounds to 1 pound of coke.

A series of twelve specimens yielded the following results:—

COKE.—EL MORO, COLORADO.

	Moisture.	True Specific Gravity.	Apparent Specific Gravity.	Per Cent. of Cells by Volume.	c.c. in 100 Grams.
Maximum	0.225	1.85	1.047	54.66	71.36
Minimum	0.025	1.61	0.766	41.47	41.56
Average (12)	0.114	1.69	0.919	45.75	50.39

Coal from the Fox Hills group of the Cretaceous is coked at Crested Butte, Gunnison Co., Colorado, for sale in the open market.

An average sample taken from the entire face of the seam, 7 feet thick, showed the following composition:—

Water at 110° C.	0.72
Volatile matter	23.44
Fixed carbon	71.91
Ash	3.93
Total	100.00
Sulphur	0.36

Analyst, H. L. Wells.

This coke is made in ovens of the beehive pattern, 11 feet 6 inches by 6 feet, the charge being about 3.75 tons, and the yield about 70 per cent. The time of coking is forty-eight hours. It is used principally by the lead smelters, in cupolas, &c., in Colorado and the adjoining country.

The composition of the coke is as follows:—

Water	1.55	...	0.41
Fixed carbon . . .	92.03	...	92.44
Ash	6.62	...	7.15
Sulphur	0.58	...	0.55

The amount of ash, as shown by six analyses by Mr. Wells, is 8.7, the percentage of silica in the ash being 4.6 per cent.; the sulphur is from 0.37 to 0.58 per cent.

A series of twelve specimens yielded the following results:—

COKE.—CRESTED BUTTE, COLORADO.

	Moisture.	True Specific Gravity.	Apparent Specific Gravity.	Per Cent. of Cells by Volume.	c.c. in 100 Grams.
Maximum .	0.171	1.62	0.968	47.01	55.48
Minimum .	0.011	1.53	0.848	37.39	38.63
Average (12)	0.073	1.59	0.907	42.96	47.59

A series of twelve specimens from the Washington City Gas Light Company, Washington, D.C., is added for the sake of comparison. This coke is such as is sold by the company for domestic use, and has been crushed and washed. Consequently, it shows in some cases a high percentage of water; it also shows, as might be expected from the method of its manufacture, wide variations in all the determinations.

COKE.—WASHINGTON GAS WORKS.

	Moisture.	True Specific Gravity.	Apparent Specific Gravity.	Per Cent. of Cells by Volume.	c.c. in 100 Grams.
Maximum .	2.529	2.07	0 911	66.39	133.49
Minimum .	0.179	1.48	0.497	46 59	51.84
Average (12)	0.802	1.74	0.772	55.66	75.48

The above results have been put on record without drawing any important conclusions therefrom; although they are very interesting and instructive, yet the investigation is only just fairly commenced, and inferences made at the present stage of the work may be materially changed by subsequent examinations. There is, perhaps, no subject on which more erroneous conclusions have been drawn from entirely insufficient and often imperfect data than that of coke, and it is especially to be desired that anything of the kind may be avoided in this investigation, which should be sufficiently extended to embrace a thorough investigation of the nature and composition of coking coals and their behaviour under varying conditions, as well as a large number of determinations of all the important characteristics of coke, so that it may furnish a basis for forming trustworthy conclusions in regard to the manufacture, the uses, and value of that material. For the sake of convenience, a table is added (p. 160), showing all the important information at present accessible in regard to the cokes examined.*

Coking in Heaps or Ridges.—The oldest and still in some parts a common method of preparing coke is in meiler or heaps, in which, however, the operation is not conducted in the same manner as in the wood meiler. No covering is employed, but carbonization is allowed to commence with

* For additional particulars of manufacture of coke in the United States, see Trans. American Inst. M. Eng.; also J. D. Weeks, "The Mineral Resources of the United States" (Washington); and "Iron Age," vol. xxxvii.

TABLE OF SPECIFIC GRAVITY, ANALYSES, METHOD OF MANUFACTURE, ETC.

Coke.—Specific Gravity, Porosity, etc. Average.

Number.	Locality of Coke Works.	Moisture.	True Sp. Gr.	Apparent Sp. Gr.	Per cent. of Cells by Volume.	Volume of Cells; c.c. in 100 Grams.	Weight per Cubic Foot. Pounds.	Sampled by
1	Broadford, Connellsville, Pa.	0.034	1.76	0.892	49.37	55.73	55.68	J. H. Bramwell.
2	Connellsville, Pa.	0.053	1.74	0.926	46.92	52.35	57.81	J. McFadyen.
3	Eagle, Kanawha, W. Va.	0.021	1.68	0.894	46.85	53.89	55.81	T. Wharton.
4	St. Clair, Kanawha, W. Va.	0.030	1.67	0.924	44.81	50.23	57.68	T. Wharton.
5	Quinnimont, New River	0.044	1.83	0.713	61.12	86.41	44.51	S. Hotchkiss.
6	Sewell, New River, W. Va.	0.016	1.69	0 793	53.19	67.39	49.50	J. C. McGuffin.
7	Stone Cliff, New River, W. Va.	0.074	1.74	0.838	51.79	62.30	52.31	N. M. Jenkin.
8	Fire Creek, New River, W. Va.	0.078	1.83	0.820	55.12	69.05	51.19	S. Hotchkiss.
9	Rockwood, Tenn.	0.192	1 69	0.935	44.81	48.55	58.37	M. M. Duncan.
10	El Moro, Col.	0.114	1.69	0.919	45.75	50.39	57.37	J. Cameron.
11	Crested Butte, Col.	0.073	1.59	0 907	42.96	47.59	56.62	J. Cameron
12	Leetonia, Ohio	0.047	1.49	0.770	47.59	62.23	48.09	E. Orton.
13	Washington Gas Works, D.C.	0.802	1.74	0 772	55.66	75.48	48.19	F. P. Dewey.

Coal.—Geological Position and Analyses.

Number.	Geological Formation.	Water.	Volatile Matter.	Fixed Carbon.	Ash.	Sulphur.	Analyst.
1	Pittsburgh bed	1.105	29.885	57.754	9.895	1.339	A. S. McCreath
2	Pittsburgh bed	—	31.36	59.62	8.23	0.784	T. T. Morrell.
3	Middle Measures (XIII)	—	—	—	—	—	
4	Middle Measures (XIII)	—	—	—	—	—	
5	Lower Measures (XII)	0.41	19.99	76.87	1.94	0.79	T. Egleston.
6	Lower Measures (XII)	1.03	21.38	72.32	5.07	0.20	C. E. Dwight.
7	Lower Measures (XII)	—	—	—	—	—	
8	Lower Measures (XII)	0.61	22.34	75.02	1.47	—	
9	Upper Measures (XIV–XV)	1.75	26.62	60.11	11.52	1.49	F. P. Dewey.
10	Laramie formation	1.14	29.97	56.32	12.57	—	H. L. Wells.
11	Fox Hill Group	0.72	23.44	71.91	3.93	—	H. L. Wells.
12	Lower Kittanning Seam	3.00	31.50	62.35	3.15	1.40	
13							

Coke.—Analyses of.

Number.	Water.	Volatile Matter.	Fixed Carbon.	Ash.	Sulphur.	Phosphorus.	Analyst.
1	0.030	0.460	89.576	9.113	0.821	—	A. S. McCreath.
2	0.075	0.412	88.655	10.055	0.805	—	A. S. McCreath.
3	—	—	—	—	—	—	
4	—	—	—	—	—	—	
5	—	—	92.62	7.23	0.665	0.050	T. Egleston.
6	—	—	93.00	6.73	0.027	—	C. E. Dwight.
7	—	—	—	—	—	—	
8	0.216	0.390	95.894	3.500	0.563	0.0096	H. Froehling.
9	—	—	—	—	—	—	
10	—	—	—	18.00	0.50	—	H. L. Wells.
11	—	—	—	8.70	0.48	—	H. L. Wells.
12	—	—	—	—	—	—	
13	—	—	—	—	—	—	

Coke.—Methods of Manufacture.

Style of Oven.	Size.	Charge. Pounds.	Yield p r Cent.	Time of Coking. Hours.
Beehive	11′ × 5′ 6″, 12′ × 6′	7,600	63	48 and 72
Beehive	11′ × 5′ 6″, 12′ × 6′	7,600	63	48 and 72
Beehive	——	——	—	—
Beehive	——	——	—	—
Beehive	9′ 6″, 10′ 6″, 11′ 6″ × 6′	6,800 to 8,500	65	48
Beehive	13′ × 6′	12,000	62	48 and 72
Beehive	11′ 6″ × 6′	9,000 to 10,000	—	48 and 72
Beehive	——	——	—	—
Beehive	11′, 12′ and 13′ × 6′	100 bushels	—	48
Beehive	11′ 6″ × 6′	4.2 tons	60 to 65	48
Beehive	11′ 6″ × 6′	3.75 tons	70	48
Beehive	12′ × 6′	——	—	72
Retorts	——	——	—	—

Coke.—Used for.

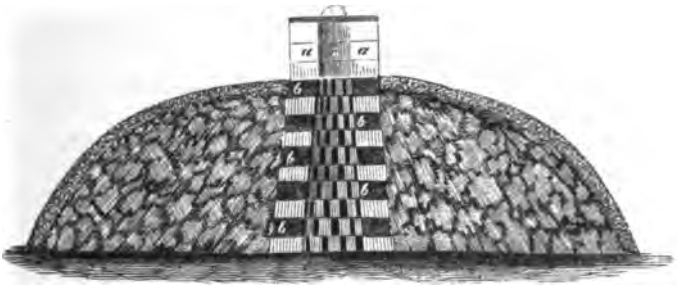
Kind of Furnace.	Size of Furnace.	Pounds Burden to 1 lb. Coke.
Iron blast	70′ × 16′	—
Iron blast, etc.	—	—
——	—	—
——	—	—
Iron blast	60′ × 16′	2.2
Iron blast	60′ × 11′	2.726
——	—	—
——	—	—
Iron blast	65′ × 14′ 65′ × 16′	2.29
Iron blast	65′ × 15′	2
Lead smelters, etc.	—	—
Iron blast	75′ × 16′	2
Domestic	—	—

NOTE.—Of the above, No. 1 is the average of nine determinations, and the others of 12, for specific gravity, porosity, &c.; of the coal analyses, No. 1 is the average of two analyses and No. 5 of four. The Coke No. 2 and the sulphur in Nos. 10 and 11 are the averages of two analyses.

free access of air, a coating of dust being first applied when the coke has already been produced, and the attention of the burner is required to prevent its further consumption. The foundation for the meiler being stationary, it becomes sufficiently covered of itself with coke débris. In order to prepare larger quantities of coke at once, long ridges are often substituted for the original round meiler, the length of which varies with circumstances and the consumption of coke; they may sometimes extend to the length of 200 feet. On erecting one of these ridges, a string is stretched along the coking station, in the direction of which large pieces of coal are placed slanting against each other, leaving a triangular space between them, so that a longitudinal channel (ignition passage) is formed, through which the string passes. In arranging the pieces, it is necessary to pay attention to the natural stratification of the coals, which should be at right angles to the longitudinal direction of the ridge. Parallel with the first series of coal, is placed a second, and then a third, and so on; but the pieces constantly diminish in size, until the station measures 6 feet on both sides. Upon this substructure the heap is then made, without particular care in the arrangement, the largest pieces below and the smallest above, until it has reached a height of about 2 feet. To facilitate the ignition, stakes are rammed in at distances of 2 feet from each other, projecting above throughout the whole length of the ridge, which, when subsequently removed, leave vacant spaces for the introduction of burning coal. The ridge, being thus kindled at more than a hundred distinct spots, soon breaks out into active combustion.

As soon as the burner observes the thick smoke and flame cease at any one part, and a coating of ash making its appearance, he endeavours to stop the progress of the fire by covering it with powdered coal-dust, repeating the operation until the whole ridge is covered, when it is left two or three days to cool. The covering on the side exposed to the wind should be the thicker, and increased in stormy weather. When the fire is nearly extinguished, which occurs in two or three days, the coke is drawn. This mode of coking is simple, but not very economical. The fire, proceeding from the upper part of the ridge in a downward direction towards the lower and interior parts, converts the coal in the upper strata into coke before that in the interior has acquired the temperature necessary for charring, and is still in want of a supply of air, which can only be furnished from without, and must not be excluded by a covering. During the time, therefore, that the inner parts of the heap are being converted into coke, the outer portions are being uselessly although unavoidably consumed. A somewhat different method has been employed in Scotland, and in other places which completely obviates this difficulty. Fig. 69 represents a section

FIG. 69.



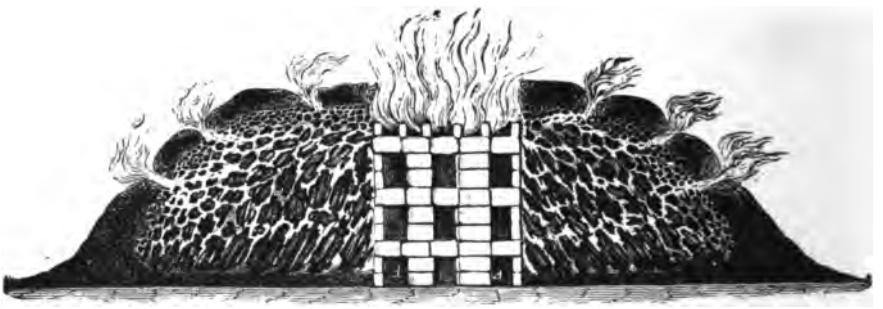
of one of these heaps, which are constructed and managed much on the same principles as the charcoal meiler.

A conical brick chimney, 3 or 4 feet high, is erected upon the coke station, 3 feet wide at the base and tapering towards the summit, apertures *b b b* being left between the bricks connecting the flue or chimney with the heap of coal surrounding it. The heaviest pieces of coal are placed nearest the chimney, and the smaller pieces towards the outside, by which arrangement the heap assumes a rounded shape. The inclination of the heap must be such that the covering of small coal or cinders with which it is enclosed may have sufficient support. The chimney is either covered with a lid, as shown in Fig. 69, or is left open as in Fig. 70, according to the method of charring employed. In both cases, however, six or eight open channels in connection with the interior of the chimney are made at the foot of the heap, to admit air, which is more requisite to keep up the combustion in coal than is the case with wood. The ignition is effected by the chimney, into which burning coals are thrown; these gradually communicate the flames to the heap through the apertures *b b*. Combustion thus commences in the centre, and extends towards the circumference in a direction opposed to that of the air. The flame and smoke escape through the open chimney. The coking is finished as soon as these cease to be evolved, and the mouth of the chimney is then closed with an iron door, whilst the holes at the foot of the heap, and any that may have been formed in the covering, are stopped up with small coal and dust.

A heap of 20 feet in diameter and 3½ feet high may be charred in this manner in about two to two and a half days, while the same time is required for the coke to cool.

Fig. 70 represents one of these heaps in the process of coking. It is

FIG. 70.

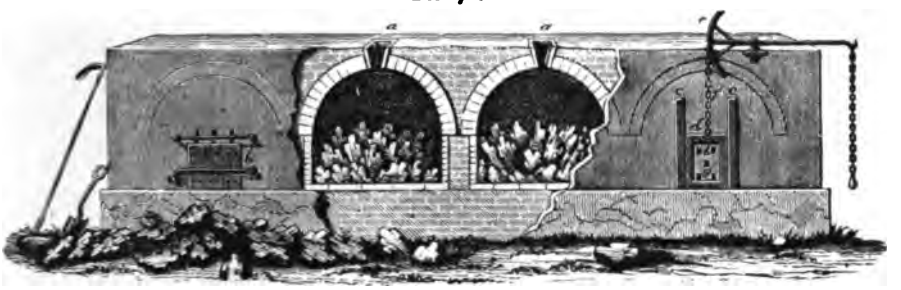


constructed, however, in a somewhat different manner, being higher than the chimney, and the flame being allowed to find its way through the covering in different parts. In other places, where similar heaps are erected, the process is conducted in a different manner, and resembles that practised with the ridges first described. No covering is then used, and the chimney is closed with an iron slab immediately after ignition. The flame then penetrates the meiler, fed by the air which everywhere has free access; as soon as it disappears at any spot, that part is protected with cinders or small coal, and so on until the whole meiler is covered. The heat is now sufficient to drive off the last portions of vapour and tar, which pass out through the chimney opened for that purpose. When these cease to be evolved, the chimney is again closed and the meiler allowed to cool.

Coking in Ovens.—In many countries, coke is more economically made in ovens. The ovens, which were formerly intended for the production of coke alone, and not of tar and gas, depend on the partial access of air, and are not worked by means of external heat. A set of coke-ovens, as

they were formerly constructed at the Tyne Ironworks and elsewhere, is shown in Fig. 71, and in horizontal section at Fig. 72. The drawings represent four ovens, ranged together in order to save brickwork and retain the heat (the arrangement shown in Fig. 85 is better). Each separate oven is a square space, constructed of brick, and arched over at the top, 10 feet deep by 12 feet wide, affording space for a mass of coal 120 feet square by 10 feet high. The whole thickness of the wall is 2 feet, including the internal lining of fire-stone. No grate is requisite, but in the centre of the arch *a*, an aperture is made 2½ feet wide, and another *b b* at the bottom of the front wall, for the introduction of the coal, which can be closed by a door

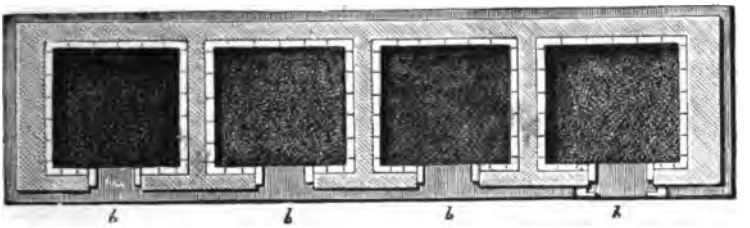
FIG. 71.



3 feet square. The aperture *a* is supplied with an iron ring, the opening *b* with an iron casing which forms a groove *c*, in which the door slides. This door consists of an iron frame, filled with brickwork, which is movable in *c*, by means of the lever *e* with its chain *f*, to which it is suspended at *d*. A number of holes *g g*, are either left in the brickwork of the door for the admission of air, or the bricks of which it is constructed are loosely put together. The first oven shown in the drawing has a door of a less convenient construction.

The ovens are charged with coal, sometimes through the opening in the roof, and sometimes from the front. The former plan of loading an oven is

FIG. 72.

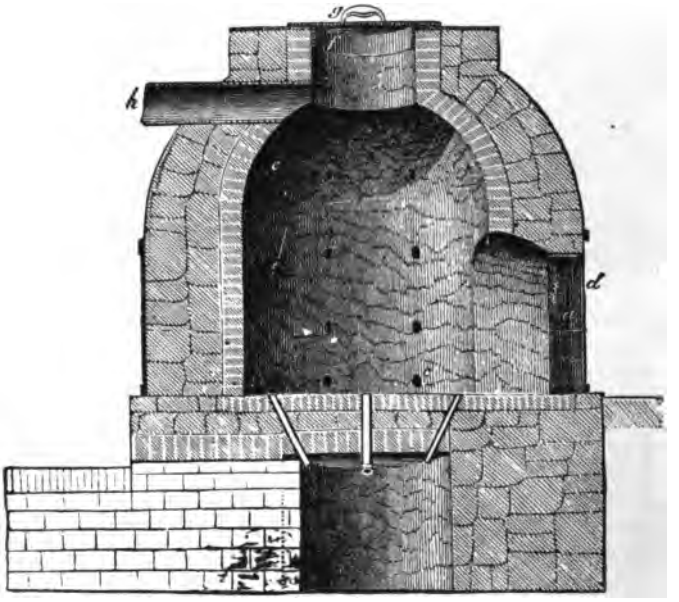


said to produce coke of less uniform quality than the latter. The reason probably is, that, being gradually charged from the front by a workman, the coal is not so dense in the centre as when it is allowed to fall in a mass from above, and consequently is more uniformly burnt. The front door is now partially closed by fire-brick tiles, which are made tight with loam or clay up to the level of the coke. If the oven is sufficiently hot, the coal ignites at the edges where it is in contact with the heated brick surface. As long as dense volumes of smoke or flame are evolved, the air is allowed free ingress through the openings in the upper tiles; but when all flame disappears, both apertures are closed as completely as possible, and the oven is allowed to cool down for a period of twelve hours and upwards. The coke is then

withdrawn by rakes, and the whole cooled down by water. The quantity of coke which one oven will hold varies from 3 to 9 or 10 tons, and the period of coking from forty-eight hours to six or seven days.

In most coal countries, although the large quantities of tar formed in the manufacture of coal-gas for illumination are carefully collected, these secondary products of the coking process were disregarded until recently. In Silesia on the contrary, the industrial relations of the country are so distinctly in favour of collecting the tar, that the ovens are always constructed with that view. In Gleiwitz, for example, the form of oven or kiln represented in Fig. 73, has been employed, which plan, in a somewhat different

Fig. 73.



form, was in use in this country—the ovens being constructed of iron, and lined with brick. These coke-ovens are about 8 feet high, of a cylindrical form, and constructed of brick. They are charged by the opening *a*, which is afterwards bricked up, and closed by an iron door *d*, the crevices in which are filled with clay; *f* is the mouth of the furnace, with an appropriate cast-iron door *g*. The air has access by the apertures *c c c*, which are ranged one above the other in rows, reaching to the arch. The lowest of these are in the sole of the oven itself, which, being supported at the sides, thus becomes a kind of grate. It is better, however, to make the sole of massive brick-work, so that the draught-holes may proceed from the sides. The tar vapours and gases are conducted during the operation through the tube *h* in the side of the arch to a cistern, which condenses and collects the former, allowing the latter to escape. During the cold season, the tube *h* leads directly to this cistern; but in summer it is carried in a zigzag manner through a water-tank, for the purpose of aiding the condensation.

In charging the oven, large lumps of coal are introduced at *a*, leaving a space for the insertion of burning coals, then smaller pieces at *f*, in all about 35 to 40 cwts. When the first portions have taken fire, the two larger apertures and the upper rows of draught-holes *c c* are closed, the lower row only being left open. As soon as the fire, as seen through

these openings, assumes a reddish-yellow colour, they are closed, and the second row opened, and so on. The first row is closed after ten hours, the second is allowed to remain open for the same time, the third row sixteen hours, and the last, or uppermost, three hours, after which the oven is left for twelve hours before the coke is drawn. With four of these ovens, eight or nine cokings can be made weekly. The Gleiwitz coal is of a slightl caking character, without being very deficient in hydrogen. One hundred parts of it produced, on an average of several months' trials, 74 parts by volume (53 per cent. by weight of coke) and about 5¼ gallons (a very considerable yield) of tar. The same coal, charred in the heaps, produced only 47 per cent. by weight of coke, which was much more porous and less dense than oven-coke, an equal bulk of the latter weighing nearly ⅓ more.

Fig. 74.

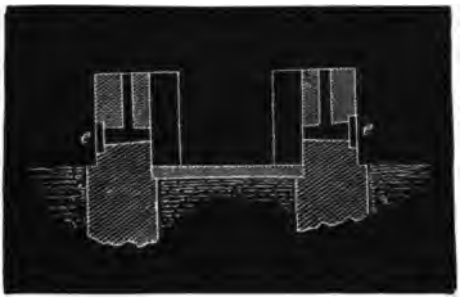


Fig. 75.

Fig. 76.

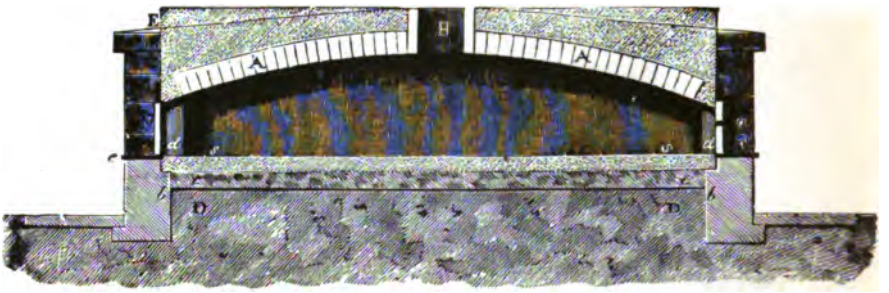
A process for coking small coal in open kilns has been very successfully carried out at the same place, the construction of the kilns being shown in Figs. 74, 75, 76. The coal is wheeled into the kilns through the openings *C* and *D*, Fig. 76, moistened with water, and well beaten down; whilst pieces of wood, 4 to 6 inches thick, are laid on the coal, stretching across the whole width of the kilns. These pieces of wood correspond with the openings or air-channels *e e e*. The kiln is filled to the level of the outer wall

in this manner, and covered with clay and coal-ashes well beaten down; the wood being then set on fire, the process is conducted with much the same precautions as in the manufacture of charcoal in heaps.

The kilns are 8 feet wide, 5 feet high, and 44 to 60 feet long, holding 200 to 300 tons, and the operation lasts from ten to twelve days. When carefully managed, the loss does not exceed 20 per cent.

The refuse coal from the pits, coal-dust, &c., which, in itself, is of very little value, can often be converted into coke, particularly if it is of a caking nature, as the small pieces become soft with the heat, adhere together, and form solid masses of coke. At St. Etienne, an attempt was made to stamp moist coal-dust into wooden boxes constructed in the form of a small heap or meiler, which could easily be taken to pieces, and were furnished with pegs on the inside, with corresponding draught-channels. These were ignited after the removal of the mould; however, they not only involved too much manual labour, but there was a very considerable loss, so that they have been supplanted by the use of closed ovens, one of which is represented

FIG. 77.

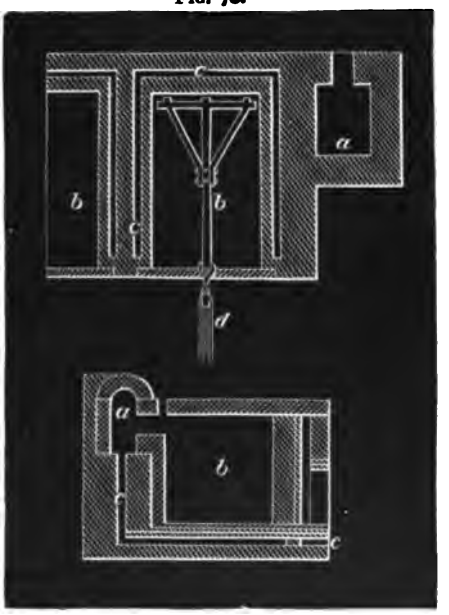


at Fig. 77, being the form employed at Rive de Gier, on the Loire. The construction is the same in principle as that of the common baking-oven; a slightly arched space with a flat sole, without grate, which, heated by the previous operation, ignites the charge. The bed of the oven *s s* is oval-shaped, 11½ feet wide by 23 feet long, composed of a mass of clay 6 inches in thickness, which is spread out and stamped upon a layer of small stones, *t t*, through the interstices of which its moisture can escape. The space *D D* below the bed of the oven is filled with earth or rubbish. The working holes *d d* opposite each other, 2.8 feet wide and 2 feet high, are placed in the lowest part of the arch, each of them being surrounded by a framework of cast-iron fixed in the wall, in which the sliding door *P* moves up or down. The door is a flat iron box, lined with brickwork to resist the heat: there is a small aperture *o* in the middle of the door through which the workman can observe the progress of the operation. The arch rises 4 feet above the bed of the oven in the centre, its highest point, where a small chimney *H* is introduced, 1.6 feet in diameter and 1.8 high. The interior of the oven, at *H* and *A*, is constructed of fire-bricks and clay; common stones, covered with a layer of mortar mixed with sand, form the exterior.

As soon as the coke from a previous operation has been removed, the oven is again charged with coal-dust, previously moistened, that it may easily cake together and yield a better produce of coke. The depth of charge should not exceed 8 inches with strongly caking coal, or 10 when it is less caking; it should be spread out uniformly, and the doors closed, with the exception of a narrow slit at the bottom for the introduction of air. The oven will hold from 60 to 70 cubic feet of coal. When the heat begins

to act on the coal, aqueous vapour and sulphurous and combustible gases are evolved; it is found expedient to prolong this stage of the process as much as possible, in order to secure a large produce of coke. This part of the operation should occupy two hours, the slight draught being only just sufficient to carry off the vapours; the evolution of aqueous vapour soon ceases, and the combustible gases passing off in greater quantity suddenly ignite with a kind of explosion, the yellow smoke ceases for a moment, and is succeeded by a black cloud. At this stage of the process, the mass of coal is at a low cherry-red heat, and it becomes necessary to increase the draught in order to drive off the whole of the vapours and volatile matter. The door is therefore raised about 3 inches, when the fire immediately draws up, and a dusky, sooty flame issues from the chimney. After three-quarters of an hour this becomes clear and white, the heat is then uniformly spread over the whole mass of coal, which begins to split and crack, and must not be disturbed. In three-quarters of an hour after these fissures have extended to the very sole of the oven, and when the whole is at a full red heat, the door is closed, and all crevices are filled with clay. The heat now generated is sufficient to complete the carbonization and to drive off the last portions of volatile matter. For a time, the flame still flickers, becoming whiter and whiter, at a considerable distance above the chimney, but gradually diminishes, threatening to die away altogether, the evolution of gas from the interior having entirely ceased. If more time were allowed, the air would, at last, enter by the chimney as the pressure diminished; it is necessary, therefore, to advance the cover until it is completely closed. The coke is now removed as rapidly as possible to avoid any loss of heat, and, the doors being quickly opened, the mass of coke is broken up with staves, raked into barrows, sprinkled with water, partly to quench the fire more rapidly, and partly to decompose the remaining sulphur compounds, the presence of which is recognized by the odour of sulphuretted hydrogen arising from the glowing coke. Another charge is then thrown into the oven, and the same process repeated, the operations occupying about twenty-four hours.

Fig. 78.



In Belgium, a series of coke-ovens of the construction shown in Fig. 78, are employed, *b b* being the body of the oven, *a* the chimney flue, *c c c* a cold-air flue in connection with the chimney; *d* represents an apparatus for drawing the whole charge of coal at once.

Figs. 79, 80, and 81 are drawings of ordinary beehive ovens, Fig. 79 being a plan, and Figs. 80 and 81 being sectional elevations on different lines. These ovens are about 10 feet in diameter, and 4 feet from the floor to the springing of the dome; and in favourable localities each oven will cost about £25: *a*, Fig. 79, indicates a series of flues under the floor of the ovens, ending in a chimney *b* (Fig. 81), the object of which is to assist in cooling the

floor as rapidly as possible after the coke has been drawn out, so that there may be no distillation of the coal of the next charge, which would tend to

Fig. 79.

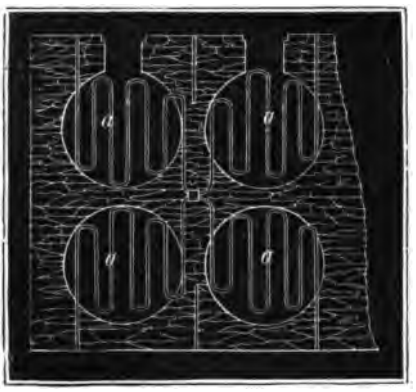


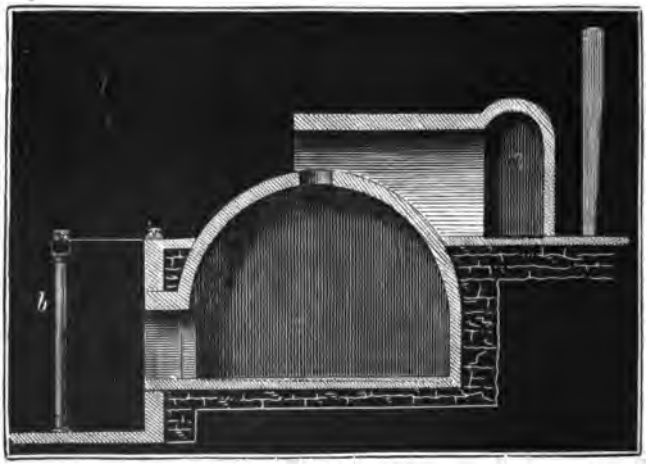
Fig. 80.

Fig. 81.

produce an inferior coke at the bottom. It may also be noticed here, that the dome ought to be made as flat as possible consistent with durability, in order to reflect the heat as much as possible down upon the coal, and preserve the heat of the oven generally.

Figs. 82, 83, and 84 show a similar form of oven, in which the smoke is, however, carried along the flues to a high chimney, thus avoiding the inconvenience of the large volumes of smoke which are poured forth by a range of coke ovens; *b*, Fig 82, is a cast-iron pillar supporting a railway

Fig. 82.



for conveying the coal waggons to any particular oven, so as to be charged in front, it having been found that when the coal is more equally spread in the ovens by manual labour, the charge is burnt off in less time than when the waggon discharges the coal into the oven all at once through the opening in the dome, independent of saving in the wear and tear of the dome occasioned by the passage of heavy coal waggons.

Fig. 83.

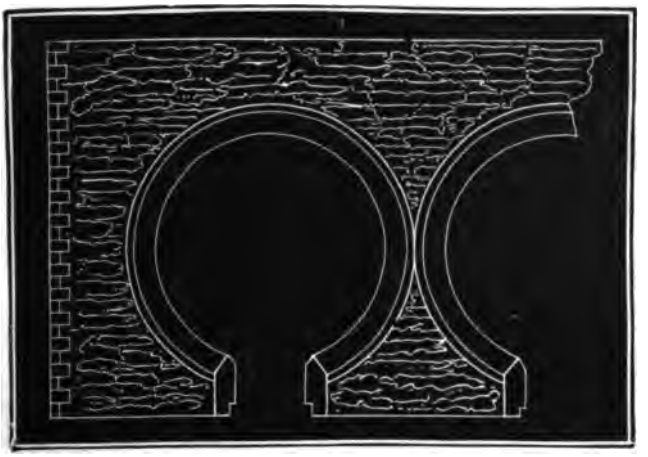


Fig. 84.

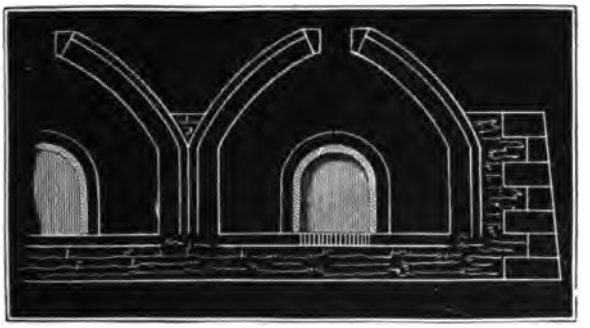


Fig. 85 represents the arrangement now generally adopted where there is a number of coke ovens, both for the purpose of economy in the construction and to carry off the products of combustion by one chimney.

A patent was secured for drawing the whole of the coke at once from the oven, so as to save labour and time, but it did not come into general use. Indeed, the great point to which attention ought to be directed is, especially to increase the yield and the rapidity of the coking process, so as to save the great waste from the escaping gases and small residual coke, technically called *brees*.

A description of all the plans of ovens which have been introduced would be too cumbrous—in fact Dr. Percy remarks that their name is legion; but there are a few well-defined points at which inventors have aimed in introducing fresh contrivances. These are—

1. The prevention, as far as practicable, of the escape of heat from the ovens.

2. The introduction of air so as most completely to burn the volatile matters evolved from the coal without burning the coke produced.

3. The utilization of the waste heat in such a manner as to cause the process of coking to proceed simultaneously in all directions.

4. Facilitating the removal or drawing of the coke from the oven with the view not merely of diminishing labour, but also of reducing as much as possible the amount of heat lost in this operation.

These objects, Dr. Percy remarks, have been accomplished in the following ways :—

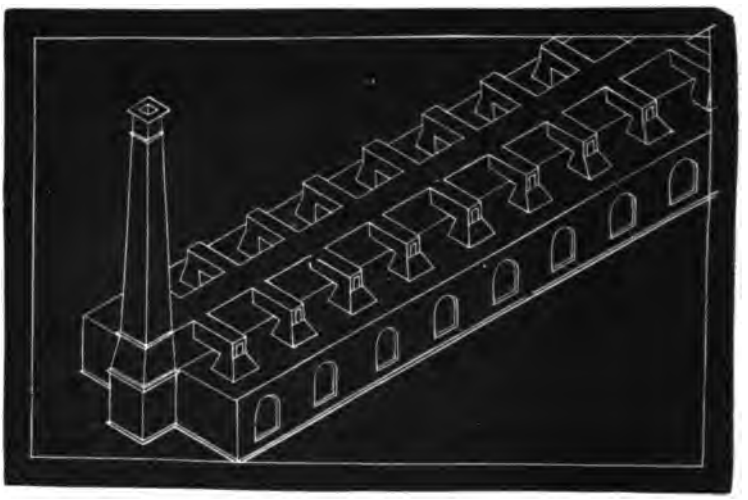
1. By making the walls thick and covering the roof with sand, or some other bad conductor of heat, by building a second arch at some distance over that which forms the roof of the oven chamber, and causing the products of combustion to pass between these arches towards the chimney, and by building two rows of ovens back to back, or a number radially round a chimney.

2. By allowing air to enter the oven only above the top of the coal in several places through channels in the brickwork, or by burning the volatile products outside the oven and so heating it like a retort.

3. By causing the volatile products of combustion to circulate through flues under the bottom and in the side walls of the oven.

4. By building the oven with dimensions tapering outwards, and the bottom sloping downwards towards the front to facilitate the use of the drag.

Fig. 85.



These remarks, however, now require some modification, because the tendency of recent experiments has been decidedly in the direction of the recovery of ammonia and tar from the gaseous and liquid products of coking, this necessitating the almost total exclusion of air from the coke oven, and leading directly to the use of those forms in which the gases produced may be employed for heating the outside of the coking chambers.

The ordinary circular or "beehive" ovens, which have been and are still a very favourite form in this country, are illustrated in Figs. 79 to 85. They are made of various sizes and with variations in details of construction, whilst the general design is adhered to. Some are built with flat roofs and two chimneys to each oven ; others are built of an elliptical form on plan, as in the case of the coke ovens used at the collieries of the Saar district, and in those erected at Camden Town by the London and North-Western Railway Company. In the latter case, all the ovens communicated with a horizontal flue along which they were built, this flue leading to a chimney stack 115 feet high.

The principal ovens in which coking is carried on by means of heat applied externally to the coking chamber, without recovery of the volatile products, are Coppée's and Appolt's ovens. The Coppée form of oven is,

however, a favourite one for the method of coking in which the bye-products are recovered; the ovens employed on this system are described farther on. Both Coppée and Appolt ovens heat a comparatively thin body of coal by combustion of the escaping gases which are led directly into passages surrounding the coking chamber.

Coppée's oven is designed for coking only finely divided or crushed coal, and is said to coke rapidly and give a maximum yield of good dense coke.

It differs from the Appolt oven in being composed of a long narrow horizontal chamber having a number of vertical flues on each side communicating with large horizontal flues which extend under the bottom of the coking chamber. The Appolt oven consists of a narrow tall vertical chamber tapering towards the bottom and surrounded on all four sides of its sectional plan with a space in which the volatile products of coking are burned.

The COPPÉE oven is a Belgian invention, which was patented in Great Britain in 1868 (No. 2152), and was described by Mr. Emerson Bainbridge in a paper communicated to the North of England Institute of Mining and Mechanical Engineers on April 5, 1873. It was in use on the Continent prior to 1861, and was introduced in 1873 and 1874 in England at Chapeltown near Sheffield, and at Ebbw Vale.

The general arrangement of a batch of these ovens is shown by Figs. 86, 87, the letters indicate the various lines on the sectional elevation across which the sectional plan has been drawn.

"The ovens are conveniently built in batches of thirty ovens, and they are worked in pairs, one oven of each pair being charged when the contents of the other are half coked, and *vice versâ*. Air is admitted to the volatile products evolved from each oven, and then the products evolved from the two ovens forming the pair are united. By this means, the rich hydrocarbons which are generated at a comparatively low temperature at the commencement of the operation of coking are raised to a higher temperature by admixture with the more highly heated products simultaneously evolved from the other oven of the pair, and are thus, it is believed, effectually burnt. The heat resulting from the combustion of the volatile products is communicated chiefly to the particular pair of ovens from which they have been evolved, by passing the gases with air through the vertical flues in the sides and the horizontal flues under the floors of the pair of ovens." The coke is pushed out at one side of the row of ovens by means of a ram worked by a rack and pinion driven by a steam engine, which is carried, with its vertical steam boiler, on a travelling carriage running on rails along the opposite side of the ovens.

The ovens erected at Ebbw Vale differ, according to Dr. Percy, from the description given in the specification of Coppée's patent in the following respects. According to Coppée's specification, a portion of the air required for the combustion of the products evolved from the coal is to be admitted to the top of the oven itself above the surface of the coal; whereas in the ovens erected at Ebbw Vale no air enters the oven, the whole of it being admitted to the flues through which the volatile products are conducted on leaving the oven. And further, in place of the one main flue at Ebbw Vale for the final exit of the gases from the whole batch of ovens, in Coppée's specification there are two, one of which contains a large boiler intended to be heated by the waste heat of the products of combustion, which can be turned at will into either of the two main flues.

The Coppée ovens are shown in sectional elevation and plan, partly in section, in Figs. 86, 87, the following being a general description of their design:—

On the top are square vertical shoots for charging the ovens. Directly under these are the ovens or coking chambers; the sides of which are

built slightly tapering from back to front to enable the coke to be pushed out at the back with facility. The ovens are 9 metres long, 480 millimetres wide at the back, 430 millimetres at the front, and 1.1 metre high to the crown of the arch. They are built in pairs and sometimes in complete stacks of thirty ovens as in Fig. 87. Alongside the ovens there are vertical flues through which the gaseous products escape from the oven. Each

Fig. 86.

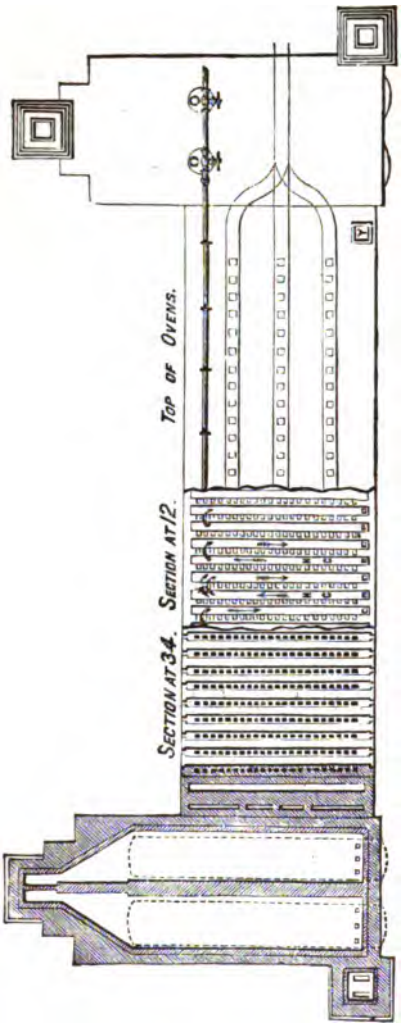
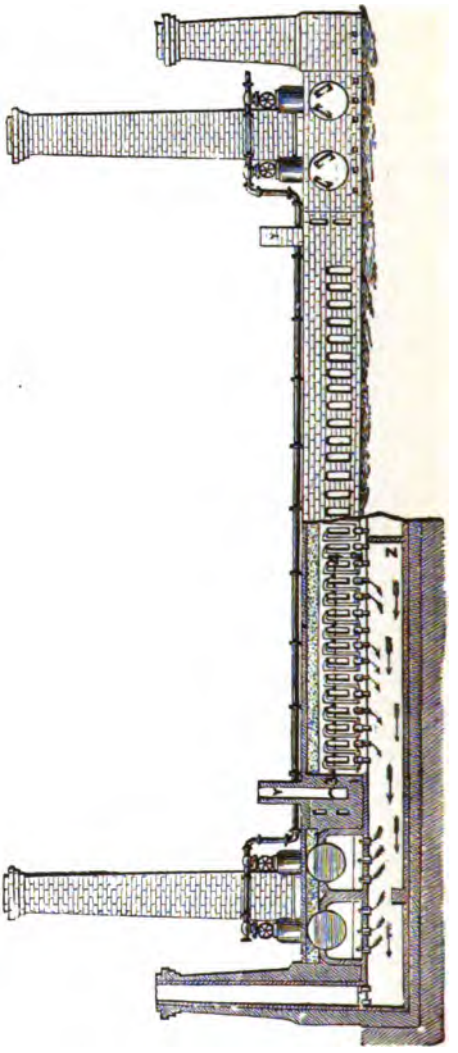


Fig. 87.



oven has a series of these flues built in one of its side walls which also forms the wall of the adjoining oven. Directly above these vertical flues and leading into them are smaller vertical flues through which air is admitted for the combustion of the gaseous products; each flue has a short square cast-iron pipe fitted with a regulating damper at its upper end.

Horizontal flues, one of which runs under each oven, are connected with

the vertical flues. The gaseous products from two ovens are led first into one horizontal flue, with which the two series of vertical flues belonging to the same pair of ovens communicate.

After the gaseous products from the pair of ovens have traversed this flue, they pass through short connecting flues, of which there are in each case two, and return in the opposite direction through the horizontal flue under the adjoining oven of the pair. By means of short vertical flues, one of which leads from each horizontal flue into the main flue, the gaseous products may be led to the chimney without traversing the return horizontal flue. At other times, these short vertical flues are closed by fire-bricks placed over their upper ends.

The main flue, which conveys away the gases from the whole of the ovens of the batch, runs across the breadth of the ovens, under them and the horizontal flues referred to.

All the gaseous products after combustion are discharged into the air either through the short chimneys or first through boiler furnaces and flues to the taller chimneys.

The end oven on the right has no series of vertical flues on its right side; in order, therefore, to heat this side, the gases, after traversing the flue beneath the adjoining oven and returning in the opposite direction through the flue beneath the end oven, instead of being at once discharged into the main flue through the vertical flue, are carried through cross flues into a horizontal flue which is built on the right side of the end oven, and from this return through another horizontal flue (built over the former flue) and thence return through a vertical flue into the main flue.

Open spaces are provided above the ovens between the vertical shoots. These spaces are left to prevent the upper part of the structure becoming too much heated. A horizontal flue, open at one end, through which air is admitted for the purpose of cooling the foundations, is also built at each end of the batch of ovens with cooling flues in connection. These are vertical flues leading from the horizontal flue to horizontal flues beneath the ovens. These latter flues run from the side to the middle of the batch of ovens; the cool air conveyed through them ascends through short vertical flues into another horizontal cooling flue, and thence passes into other cooling flues which are connected with the main horizontal flue and with each other by small cross flues. Finally, the air passes into a chimney flue and thence to a small chimney, the draught in which keeps a current of air constantly circulating through the cooling flues.

The oven doors consist of an upper and a lower door, which can be opened independently of one another. The doors in the front and back of each oven are alike, except in width, the difference in this respect corresponding with the difference in the width of the two ends of the oven itself.

The ovens are charged with crushed and washed coal, which is run out of suitably shaped trucks and into the ovens by the openings on the top. The process of emptying the oven of coke and refilling it with coal does not occupy more than eight minutes. The coke is quenched with water outside of the oven, from which it is pushed in a solid block at one operation by a ram. It is of course broken up in order to facilitate the quenching. Each oven cokes six charges per week and each charge yields about 2 tons of coke.

Experiments at Ebbw Vale showed a yield of coke amounting to 62.5 per cent. on the unwashed coal used, but as the coal contained nearly 20 per cent. of shale, the percentage yield of coke must have been higher, although Mr. Richards found 6 per cent. of water in the coke. This quantity of water is not, however, a necessary feature of this method of coking, but merely argues careless quenching.

Dr. Percy mentions 0.8 per cent. of water as the result of a series

of determinations made by Messrs. Bolckow, Vaughan & Co., at their collieries.

The cost of coking at Ebbw Vale is stated to have been one shilling per ton of coke, not including cost of crushing and washing the coal. The steam for crushing and washing was, however, generated by the waste heat from the ovens.

The APPOLT coke oven differs from all others in being a vertical shaft or chamber rectangular in section, in which the coal is coked by the combustion of the volatile products of carbonization in spaces surrounding the chamber. The coal is charged at the top, and the coke is withdrawn through an iron door below, the oven being tapered outwards from top to bottom. This form is very convenient in providing a large heating surface in a small space; the construction is a more solid one than in ovens having arched roofs and passages, and the advantages of easy charging and withdrawing the coke are apparent. In a series of twelve ovens, each about 4 feet long and about 1 foot 6 inches wide at the base, and about 3 feet 8 inches long by 13 inches wide at the upper part, and about 13 feet high, the extent of heating surface obtained by the peculiar subdivision of this mode of construction was nearly 2045 square feet for a total charge of about 17 tons of coal—a surface which is said to be two or three times greater in proportion than that of the most improved kind of other ovens. Another advantage derived from this large amount of heating surface is that the heat of combustion of the volatile products is utilized to a much greater extent than in other ovens, less heat being lost by radiation from the external surfaces of the ovens.

The ovens are actually closed chambers and resemble retorts, having only such apertures—which are common also to retorts—as are required for the escape of the volatile products of carbonization. No air from outside can reach the interior of the coking chamber, even though there may be cracks in the walls, because of the internal pressure of gas escaping from the coal, and also because in the space surrounding the oven combustion of the gas is going on. In ordinary ovens, air is admitted, and the quantity may by carelessness become excessive, of course causing waste of coke. This cannot happen with the Appolt ovens, and the exclusion of air from the interior of the coking chamber has other advantages also.

The combustion of the gases evolved is said to be more perfect and active than in ordinary ovens, because air is admitted through numerous openings in the outer walls, and there is a considerable space available for a combustion chamber in which the gases and air mix and unite. The openings from the coking chamber for exit of the gases are also numerous and small, so that rapidity of admixture with air and combustion are promoted by this means. As a result, the ovens are maintained at the required temperature, which is well distributed through every part, and changes of temperature to which other ovens are subject at charging and drawing are prevented. The drawing of the charge is rapidly and easily accomplished, the coke falling through the iron door at the bottom into iron waggons placed to receive it; the shape of the ovens also facilitates the charging with fresh coal. The rapidity with which coking is effected in this oven has led Dr. Percy to suggest that it should be used for making coke from non-caking coal, which he found would produce a solid coherent coke if rapidly exposed to a high temperature in a closed vessel.

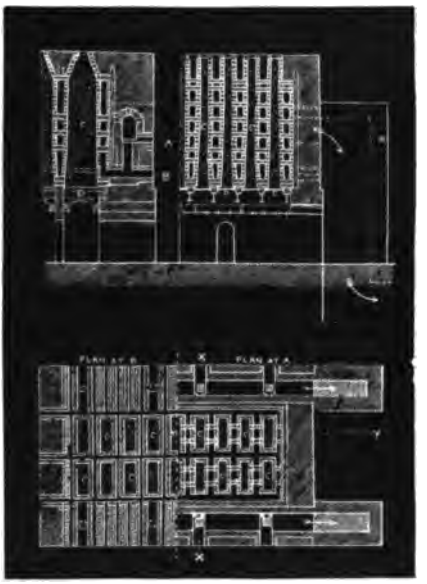
The yield of coke from ovens on this plan which were lighted on September 1, 1857, at Marquise, in the Department of Pas-de-Calais, France, and worked till June 1858, is given by the Messrs. Appolt as follows:—Each compartment contained from 1350 to 1400 kilograms, or somewhat less than 1½ ton of coal. The coking was completely effected in twenty-

four hours, and four men were required for charging and drawing. Belgian caking coal gave from 80 to 82 per cent. of coke, and English caking coal from 72 to 73 per cent.—but no analyses of the coke are given nor statements as to the yield from same coal in other ovens. The quantity of gas given off was found more than sufficient for coking, so that steam might be raised by the excess of gas.

Another statement (Wagner's Technology) gives the yield of coke from Duttweil coal with Appolt ovens at 66 to 67 per cent., whilst with ordinary ovens the same coal yielded 61 per cent.

The Appolt oven costs from £560 to £600 to build, and is thus much more costly than the ordinary kind, but it gives a larger yield and is more durable than the latter. The ovens referred to at Marquise are illustrated by Fig. 88.

Fig. 88.



"The structure consists essentially of a large rectangular brick chamber about 17 feet long, 11 feet 6 inches wide, and 13 feet high, divided by partition walls about $4\frac{3}{4}$ inches thick into a series of twelve compartments, each of which is a coking chamber or retort, about 4 feet long, 1 foot 6 inches wide at the base, and about 3 feet 8 inches long by 13 inches wide at the upper part.

"Each compartment has its own walls, and is surrounded by a free space from top to bottom; and all the similar spaces thus existing round the twelve compartments are in free communication, forming in reality one continuous space. The distance between the corresponding walls of neighbouring compartments varies from about $7\frac{3}{4}$ inches to $9\frac{3}{4}$ inches. The series of compartments is contained within four vertical walls of fire-brick, between which and the mass of brickwork on the outside is a space filled loosely with some substance in powder which is a bad conductor of heat, and which will, in a certain degree, permit the expansion of the brickwork within. All the compartments are connected solidly together by strong fire-brick ties extending across the free spaces. At the top of each compartment is an opening formed by the walls on the narrow sides rising vertically, and the other sides being stepped inwards, and the bottom of the oven is open and provided with a cast-iron door about $\frac{3}{4}$ inch thick. The partition walls are carried upon cast-iron supports or girders, and are pierced with several rows of small horizontal openings ($5\frac{1}{2}$ inches by $\frac{3}{4}$ inch) at different levels. Through these openings the volatile products pass into the surrounding spaces in which they are burned with atmospheric air admitted through openings in the outer walls"

These ovens leave but little to be desired in completeness of design, but, although the economy in time of coking and larger yield obtained by the use of such ovens has long been proved, it seems there is still amongst iron-masters a preference for the coke made from ordinary beehive ovens, with admission of air to the coking chamber. From a paper read by Sir I.

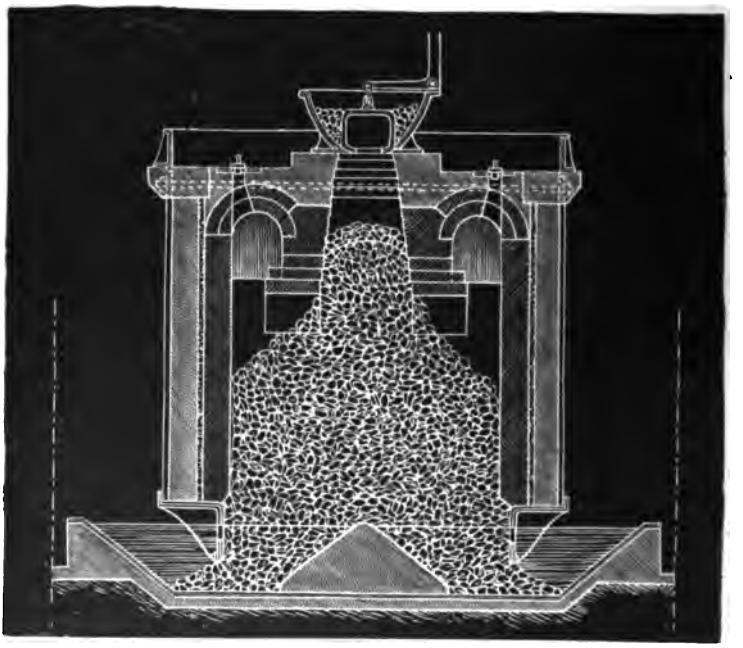
Lowthian Bell (Proceedings Inst. M. E., July 1871) at Middlesbrough, it appears that he made trial of the Appolt oven as well as of the ovens of BRECKON & DIXON and of PERNOLET, and yet decides against all forms of flued coke ovens and in favour of the coke made in ordinary ovens without flues.

It is possible that the reason of the slight inferiority of coke made in ovens heated externally may be due to the heat not being maintained at its highest point until the end of the operation, in consequence of the yield of gas being considerably diminished in the later stages of coking. If this should be so, it would be easy either to maintain the temperature by the application of regenerators, as was suggested by the late Sir C. W. Siemens,* or to produce an increased temperature towards the conclusion of the coking operation by forced combustion with heated air.

Meantime, chemical examination of varieties of coke throws some light on differences in their behaviour in blast furnaces, which consist in a variation of heat-producing power, and of power to resist the dissolving action of carbonic acid. There seems to be also promise of result in the direction of microscopic examination, or in investigations such as those which have been made by Mr. Frank P. Dewey, of Washington, on the Porosity and Specific Gravity of different kinds of Coke, and by Mr. John Fulton,† on the Physical Properties of Coke.

Two special forms of coking ovens for the production of breeze or small coke from ordinary non-coking coal-slack are described in Percy's Metallurgy

FIG. 89.



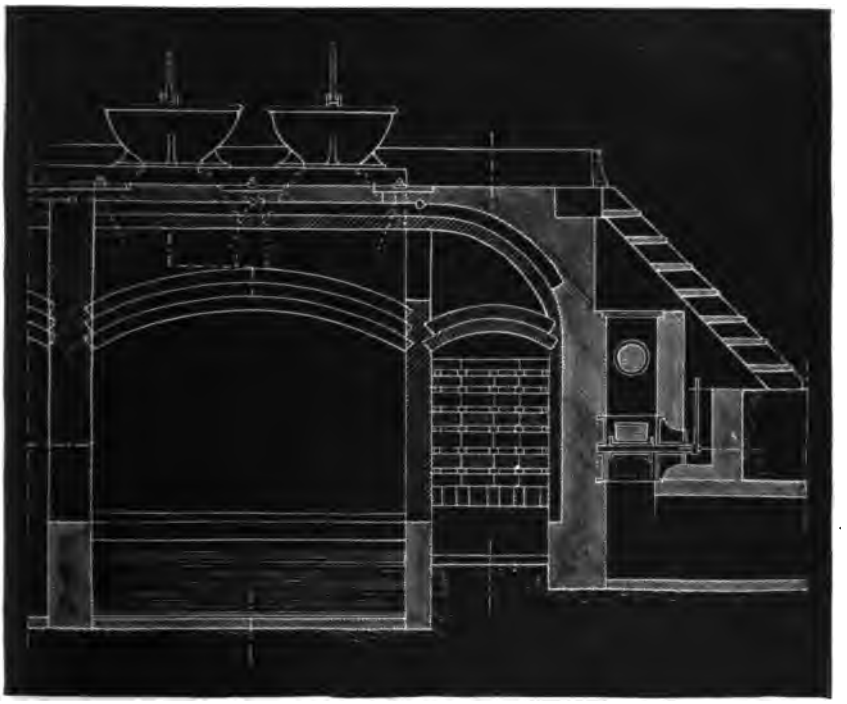
(pp. 454-459), and should be mentioned. These are the oven of Mr. J. DAVIS and the gas and breeze oven of SIEMENS—the first works inter-

* This has been done in recent forms of the Simon-Carvès oven, in Otto's oven, and some others.

† "Trans. American Inst. Mining Eng.," Oct. 1883, on "The Physical Properties of Coke as a Fuel for Blast Furnace Use."

mittently, whilst that of Siemens works without intermission. Both have the same object in view, that is, the preparation of a sort of cinder-coke from non-caking slack, and in the Siemens design the gases evolved are used in other heating operations, so that it is in reality a gas-producer, the fuel of which is withdrawn after it has been merely coked, and before the solid carbon has been consumed. A pair of regenerator chambers is combined with the gas-producing chamber for the purpose of abstracting and storing the heat of the escaping gases, which is then used to heat the air admitted to the producer for combustion of the fuel there. This is a device which has been re-patented in recent times by subsequent inventors.

FIG. 90.

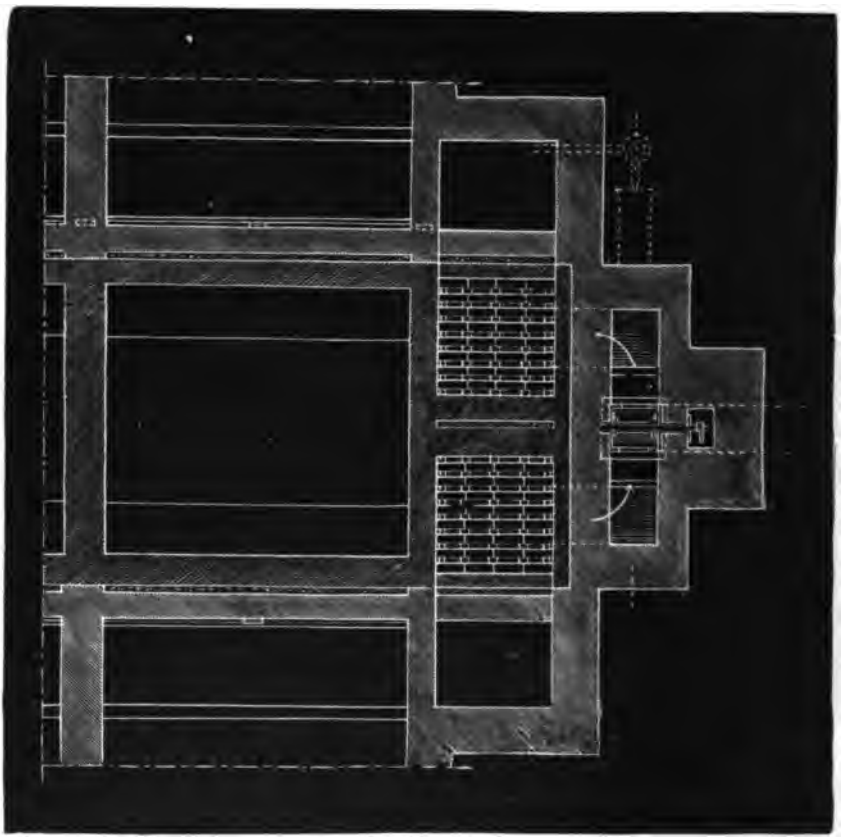


Figs. 89 to 91 illustrate this oven of Siemens, Fig. 89 being a vertical section through the producer or fuel chamber and one of the feeding hoppers; Fig. 90, a longitudinal section showing one of the regenerator chambers, the reversing valve and gas flue in front of the fuel chamber; and Fig. 91 being a ground plan in section of the whole erection, showing two such ovens built back to back. The side walls of the oven or producer are carried on cast-iron beams or bearers, shown in Fig. 89, which span a trough filled with water into which the lower edges of the beams dip in order to make a water-seal against the escape of air or gas. The air for combustion is delivered to the reversing valve chamber by means of a pipe and steam-jet shown dotted in Fig. 91. The water-trough allows the coke or breeze to be removed periodically, without interrupting the working of the oven.

Davis's breeze oven is shown in Figs. 92 to 94, Fig. 92 being a vertical section through the breeze oven or coking chamber, Fig. 93 a front elevation of the whole building, and Fig. 94 a sectional plan. In working this oven, after a fire has been lighted on the grate *a*, and a considerable layer of

incandescent fuel has been allowed to accumulate, the ash-pit door *g* is closed, and kept closed till the end of the operation. Slack is charged through the door *b*, and spread uniformly over the fire, the door being shut as quickly as possible. The gases given off from the coal pass off by the flue *d*, over the adjoining grate *e*, their heat of combustion being utilized by means of the steam-boiler *f*. Fresh charges of slack are thrown in as soon as gases cease to come off from the previous one, and this operation is repeated until the oven is fully charged. The coke is then extinguished and quenched by a jet of water directed on to it through *b*, and withdrawn through the

FIG. 91.



large door immediately under *b*. During this part of the operation, a fire is kept up on the other grate *e*, in order to keep steam in the boiler.

Recovery of Ammonia and Tar in Coking processes.—The loss of all the volatile products given off so abundantly during the process of coking, and, where air is admitted to the coking chamber, the inevitable loss also of some of the carbon by combustion, are too palpable not to have frequently attracted attention and led to attempts at their prevention.

The earliest suggestions on the subject are contained in the Treatise published by Genssane in Paris in 1770, and in the patents of the Earl of Dundonald, 1781, of W. E. Newton, 1852, and of E. Jones, 1859; but the process introduced by Pernolet (Proc. Inst. C.E., May 10, 1864) seems to have been the first attempt in this country to carry out on a large scale the

manufacture of coke along with the recovery of the various products of distillation. The Knab oven was introduced in France in 1356, but was modified by Carvés, who subsequently introduced the oven which bears his name.

Fig. 92.

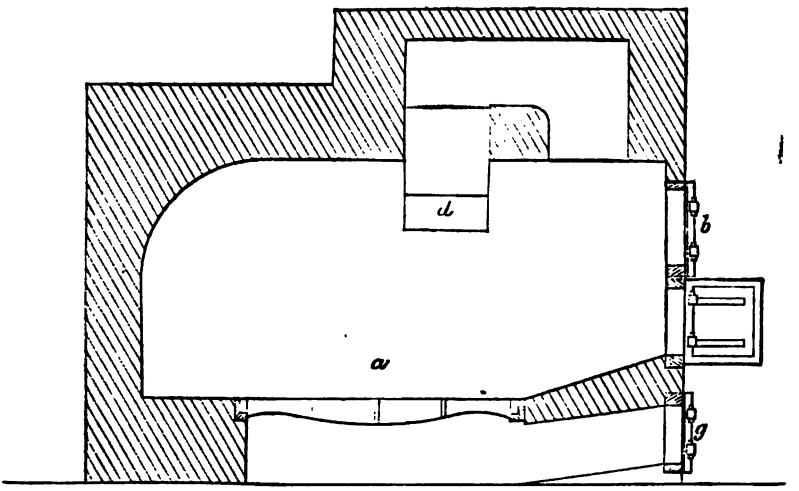
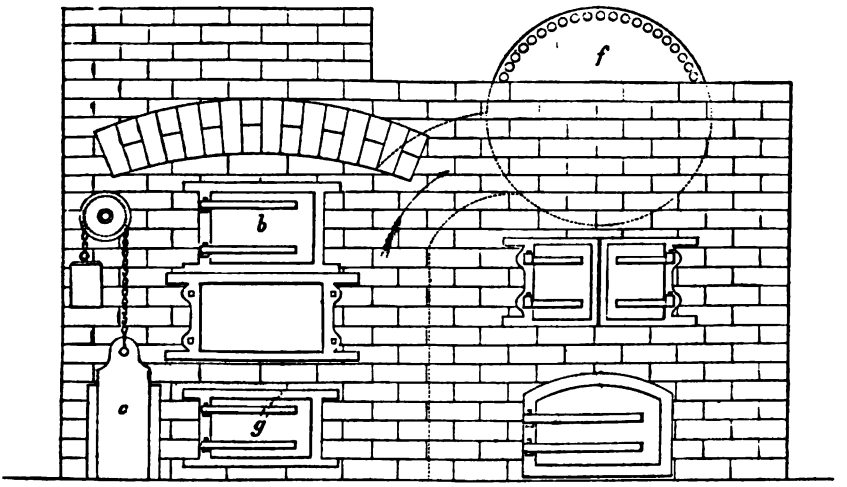


Fig. 93.



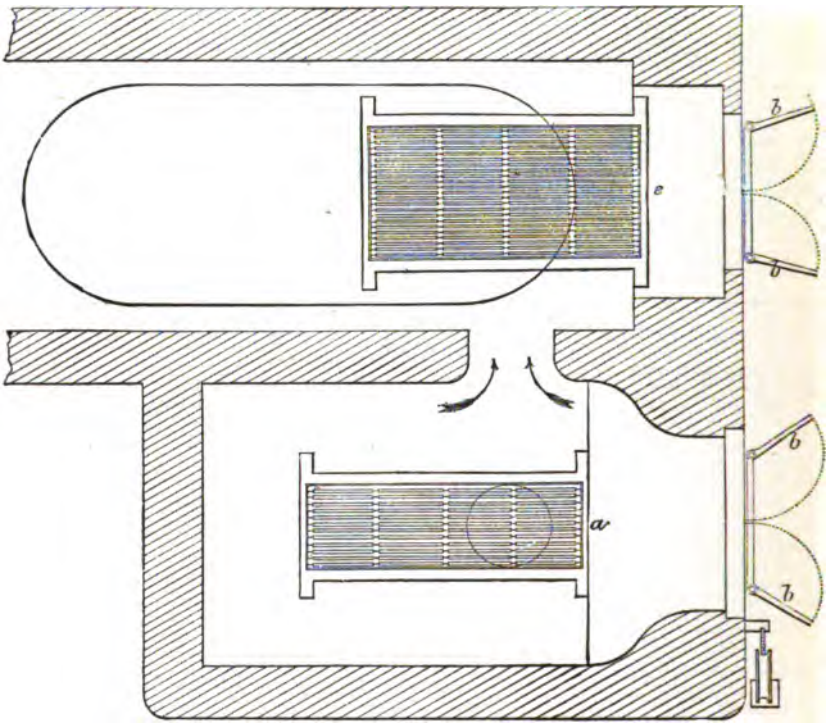
Genssane describes the process carried out at the ironworks at Sulzbach; this yielded coke and bituminous products which were used for lighting. There is no mention of the utilization of either the gas or ammonia in this process of coking, which was carried out in closed chambers of fire-brick heated on the outside.

W. E. Newton's patent mentions ammoniacal compounds as condensable products recoverable from coking, and describes the use of the combustible gases as fuel mixed with atmospheric air. The patent was for the use of an apparatus adaptable to ordinary coke ovens by which the various products might be drawn off and led to separating and condensing chambers.

The process of Mr. E. JONES was seen in operation by Dr. Percy, at Russell's Hall Ironworks, near Dudley, in 1860, and was applicable to open heaps, an underground flue being connected with the bottom of the central chimney, through which the volatile products were drawn by chimney draught, to the condensing apparatus in which they were caught.

PERNOLET'S process was introduced at St. Etienne, where ordinary ovens were converted into Pernolet ovens at a cost of about £20 each. It was also used at various other places in France and Belgium, where it was said to have been tested by many years' experience with favourable results. These are said to have given from 69 to 70 per cent. of coke at Paris, whilst at St.

FIG. 94.



Etienne the yield of coke was increased from 58.8, which was the former practice, to 69.3 per cent., and generally the increase in the yield of coke by using Pernolet ovens was from 10 to 15 per cent. About 3 per cent. of tar and from 10 to 13 lbs. sulphate of ammonia per ton of coal carbonized were also obtained.

In England, Messrs. Bell Brothers and the Wigan Coal and Iron Co. made extensive trials of the system, and the results of these trials are published by Percy and by A. L. Steavenson in Transactions of the N. of England Inst. of Mining and Mech. Engineers (1873, xxii. 3, &c.) Sir I. Lowthian Bell admits (Percy's Metallurgy, Fuel, p. 496) that the yield of coke obtained was equal to 64 per cent. of the coal used, whilst 6 gallons of tar per ton were also obtained. The quantity of ammonia was not, he says, very accurately kept, but he considers that the yield of coke was "fully 5 per cent. better than that of ordinary ovens in which the evolved gases are burnt inside

the oven instead of outside, as happens in the oven in question. This and the tar," he adds, "no doubt are important matters; but the expense of manufacturing the brickwork and the general increase of labour, &c., went far to absorb all the gain in these respects. There is a second disadvantage which I have found to attend more or less all ovens from which a better yield of coke is obtained from the coal, namely, the inferiority of the product for iron-smelting purposes."

Steavenson gives results from both Bell Brothers' and the Wigan Co.'s Works. At the former, continued trials gave

For 100 tons of coal distilled:

Coke	68.0 per cent.
Tar	2.4 ,,
Ammoniacal water .	5.2 ,,
	75.6 ,,

In addition to this, he estimates the "black ends" or inferior coke at 3½ per cent., this coke being burnt on the grates beneath the oven floors; and he assumes that there were other losses, amounting to 2½ per cent., arising from inability to connect the ovens with the condensers when first started, and until the air and moisture were expelled. This accounted for 82 per cent., which was made up of coke, tar, and ammoniacal water; the remainder, or 18 per cent., being gas, which was burnt beneath the floors of the ovens, but was never exactly measured. The ammoniacal water was treated in the usual way for the manufacture of sulphate of ammonia, and this was produced during many months.

During one period of five months (selected merely because some special statistics were available), from 7591 tons of coal 70,676 gallons of ammoniacal liquor were obtained, which yielded 14 tons of sulphate of ammonia, or 0.185 of a ton per 100 tons of coal. The amount of nitrogen in the coal used is not given.

Steavenson remarks that these results might be slightly improved by having reservoirs to allow the liquids to rest for a week; and the production of ammonia might be increased by the introduction of means to remove it thoroughly from the gas, as it is supposed a considerable portion escaped with the gases which were burnt. This might be effected either by having water or liquor circulated in the condensers in showers or spray or by passing the gas through sulphuric acid. It is estimated that by such precautions the yield of tar might have been increased to about 3 per cent., and the sulphate of ammonia to about 0.3 per cent.

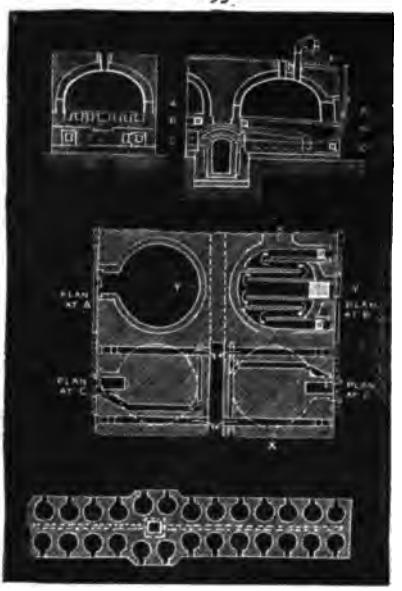
At Wigan, a slightly better system seems to have been adopted. The ovens were exhausted and the volatile products driven by pumps through condensing apparatus, consisting of eight cylindrical towers about 15 feet high and 5 feet in diameter, into which water was pumped and used over again until it acquired a proper degree of strength. Part of the gas was used for illumination, and the rest was burnt under the ovens. The products of combustion passed round the top of the oven before escaping, but this was contrary to the opinion of Steavenson, who held that the top of the oven should be kept cool until the coking reached it in the usual course as it proceeded from the floor upwards.

The charge for an oven 11 feet in diameter was 5 tons of small washed coals. The yield of coke was about 60 per cent., which is stated to have been good for the coal of the district, and of sulphate of ammonia 0.26 per cent., or rather over a quarter of a ton per 100 tons of coal coked, or about 5.6 lbs. per ton of coal.

The Pernolet oven is illustrated in Fig. 95, showing, at B, the floor

which is raised about a foot above the floor of an ordinary beehive oven whilst underneath at C is the fire-grate, with the flues between it and the floor. The opening in the roof for the abstraction of the volatile products is shown, and also the pipe for conveying these to the condensers.

Fig. 95.

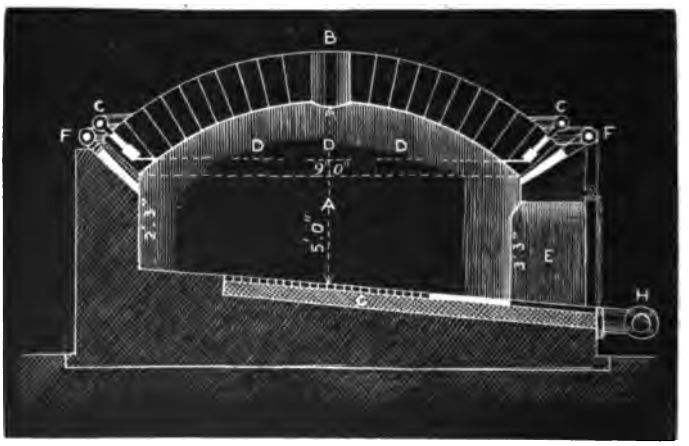


There are the usual openings in the roof for charging, to which an iron funnel and door and rails for the waggons carrying the charges are adapted.

The chimney flue for the products of combustion runs between the rows of ovens, and the chimney is placed over it where convenient. At A, is the ordinary opening used for charging and emptying beehive ovens, which is fitted with a door and means for luting and fastening the same. The gases from the condensers return to the ovens by a pipe, and enter the combustion chamber under the floor and above the fire-grate.

The next attempt to adapt means for the recovery of tar and ammonia to the beehive form of oven was made by Mr. Henry Aitken, of Falkirk, who in 1874 published (Proc. N. of England Inst. of Mining and Mechanical Engineers, vol. xxiv.) a description of some ovens erected at the Almond Ironworks, near Falkirk. These ovens were simply fitted with an improvement consisting of a pipe for conveying blast (hot or cold air), which was admitted through small openings in the roof distributed equally round the

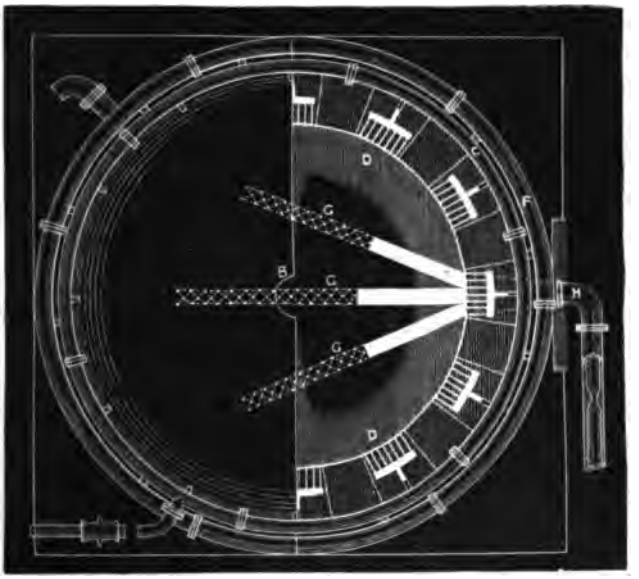
Fig. 96.



circumference. The use of the blast increased the temperature of coking, and reduced the time required for the operation. A pressure of gas was also produced inside the oven, and it was an easy additional step to insert an opening for a pipe or pipes in the bottom of the oven for the purpose of

drawing off the tar and other products. This accordingly was next done, and in 1879 (vol. xxix. of the Proceedings above mentioned) Mr. Aitken published an account of his work with these improvements, to which he added the forcing in, by the pipes in the roof, of some of the combustible gas drawn off below. Figs. 96, 97, show the plan of his oven as thus arranged. Fig. 96 is a vertical section of an oven at the centre line, and Fig. 97 is a plan, half in section. A is the main body of the oven, B the opening in the roof for filling it with coal, C the pipe for the air blast, and D the openings around the roof for delivery of the blast, E is the door for withdrawing the coke, F is the pipe by which the combustible gas was delivered to the inside of the oven, whilst G G are the channels in the floor of the oven by means of which the tar and condensable products were collected and conducted to the pipe H, which in turn led them to the condensers.

FIG. 97.



Mr. Aitken stated that he obtained about 5½ lbs. sulphate of ammonia and 10 to 11 gallons of "heavy" oil (or tar?) per ton of coal, the yield of coke being within 1 or 2 per cent. of the quantity obtained by working with a retort, and the quality being fully equal to that produced in the best practice with beehive ovens.

It appears from a statement made by Mr. John Jameson ("Jour. Soc. Chem. Industry," vol. ii., March 29, 1883) that an oven of a similar character to Aitken's was patented in October 1880 by a Mr. Henry Clay Bull.

The JAMESON plan is a comparatively recent improvement of the beehive oven, which has attracted (along with a plan to be subsequently described) a large amount of attention from metallurgists and ironmasters.

Full descriptions of it, as well as expositions of his theory of coking, have been published by Mr. Jameson in the Proceedings of the Inst. M. Engineers, part 2, April 1883, in the "Jour. Soc. Chem. Industry," vol. ii., 1883, p. 114, and in the "Journal Iron and Steel Inst.," September 1883.

Mr. Jameson contended that beehive ovens, worked in the usual way, and especially when worked in his way, must be better than externally

heated ovens, and even than such ovens as those of Aitken, in which the heat of coking is got by burning the evolved gas, because by burning solid carbon in them a higher temperature is produced than can be obtained by burning the gas, it being admitted that the higher the temperature, the better it is for coking. This contention, however, is not sound, for in the ordinary oven it is undeniable that it is the evolved gas which for the most part sustains the combustion inside the oven, although some of the coke may be consumed also. In the case of the Jameson oven, if all the gases are withdrawn, combustion must, of course, be sustained by solid carbon alone, but this must mean a much reduced yield of coke. Besides this, it is well known that with proper arrangements for heating the air for combustion, and by reason of the smaller quantity of air which is required, it is possible to obtain a higher available temperature by the combustion of carbonic

FIG. 98.

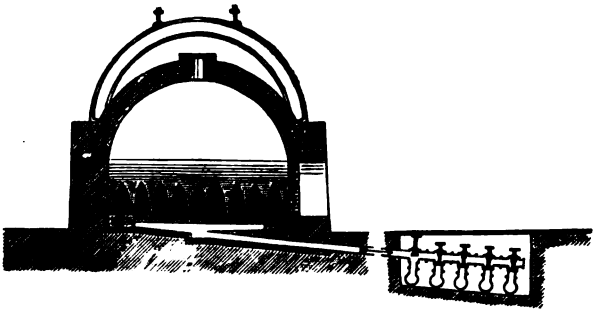
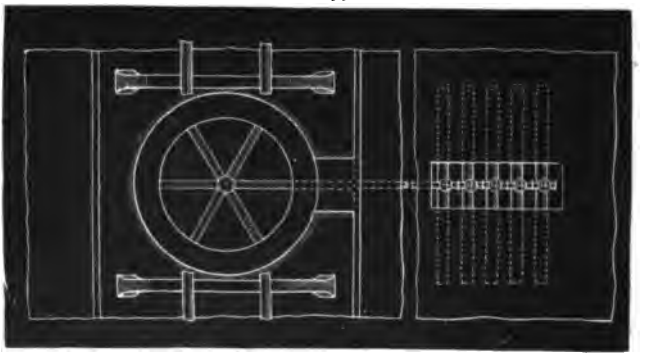


FIG. 99.



oxide, than by the combustion of carbon in the solid state under ordinary conditions. Mr. Jameson confined his comparison to one between hydrogen and carbon. So that it is probable we must seek in other directions for reasons why the beehive form of oven must be superior to all others.

It is difficult to see how Mr. Jameson's explanation of the action which takes place in coking (given in his paper in Proc. Inst. Mech. Engineers) argues in favour of his plan. He supposes a seal which divides the coke from the raw coal, and in coking in the ordinary way this seal presents a barrier to the rapid spread of the heat through the coal, thus preventing the mass being slowly distilled. But in the Jameson plan, as illustrated by his drawings and in Figs. 98, 99, this seal is broken through by the partial passage of heat to the bottom of the oven while portions of the charge are still in the state of raw coal there. Moreover the passage of the heated

gases must, even if they escape at 180° F., produce a slow distillation of the coal in advance of the real coking process, and it has to be proved whether this is an advantage or the reverse.

Mr. Jameson's plan is an extremely simple one structurally considered. He introduces no change in the ordinary beehive oven except to form channels—radial or otherwise—in the bottom of the oven, covering these with perforated quarls or tiles, and connecting them outside the oven with pipes leading to apparatus for producing a slight suction or exhaust (= about 1 inch of water), and for discharging the gaseous and liquid products where required.

The cost of applying the process is said to be small (but in many cases must involve considerable reconstruction of the oven bottoms, as they must be made secure against the admission of air) and the outlay for repairs not large. In this respect there is a decided improvement on the Pernolet plan, because the high cost for repairs practically condemned that method in England.

The yield of coke in Jameson ovens varies with different coals from 25.43 per cent. to 69.14 per cent., as shown in the following table, and generally averages the yield obtained from ordinary ovens without his improvements. The quantities of sulphate of ammonia and tarry oil are also given below. No account is taken of the gas, which is not utilized in this plan.

Name of Coal.	Hours Coking.	Coke per Cent.	Sulphate of Ammonia per Ton.	Oil per Ton.
			lbs.	Galls.
Sherburn	71	62.23	3.2	4.6
"	80	61.45	2.7	4.7
"	83	60.52	3.7	4.4
Brancepeth Cannel	88	64.13	6.	11.3
" "	88	59.68	6.1	13.1
Castle Eden Duff	88	48.12	3.2	5.6
" "	88	53.57	5.4	5.6
South Tanfield	72	60.95	3.	1.3
" "	63	59.21	1.7	4.3
Cambois Duff	113	—	13.9	4.4
" "	87	34.12	17.7	7.8
Longhirst Best	62	53.55	15.5	9.3
" "	58	41.89	11.9	12.9
Longhirst Small	66	25.43	10.9	7.8
Garesfield	84	62.42	6.6	6.1
"	84	64.21	4.9	5.
Sherburn Low Main	88	65.76	3.0	5.6
" "	88	63.85	5.3	4.8
Wharncliffe Silkstone	83	50.53	3.9	3.3
" " (crushed)	61	50.37	3.3	4.6
New Brancepeth	88	58.51	5.3	3.
Whitburn Small	89	51.38	6.8	11.8
Medomsley	70	65.	2.5	3.2
Redheugh Splint	80	69.14	3.6	4.
Coxlodge Small	80	64.83	8.7	5.8
Averages	—	56.28	6.3	6.2

NOTE.—Many of these coals are not coking coals.

The plan introduced in Britain under the joint names of SIMON AND CARVÉS, and in France and Belgium as the Carvés oven, is, as will be seen from the drawings, a modification of the Coppée form of oven with special arrangements for leading off the gases as they are evolved from the coking chamber direct to condensing and scrubbing plant, from which they are led

back to the flues of the ovens and there consumed with atmospheric air in order to produce the heat requisite for the operation of coking.

Illustrations of this system and details of cost of construction and working are given in papers by Mr. Henry Simon, C.E. ("Jour. Iron and Steel Inst.," No. 1, 1880), and by Mr. R. Dixon, of Messrs. Pease's Collieries Darlington ("Jour. Iron and Steel Inst.," Sept. 1883.)

The yield of coke from these ovens as worked at Pease's West, Darlington, has been proved to be 77 per cent., and the bye-products amount to 6.12 gallons of tar, worth 3*d.* per gallon, and 27.70 gallons of ammoniacal liquor (of 6 to 7 degrees Twaddell, worth one penny per gallon), per ton of coal. The cost of these ovens as compared with ordinary beehive ovens is as 3 to 1; the cost of working per ton of good coke, including all labour, is given by Messrs. Pease's manager at 2*s.* 3.96*d.*, but the yield of coke being 15 per cent. greater than from ordinary ovens, and the bye-products amounting to nearly 4*s.* per ton of the coal used, a very large balance of profit in favour of these ovens is soon run up.

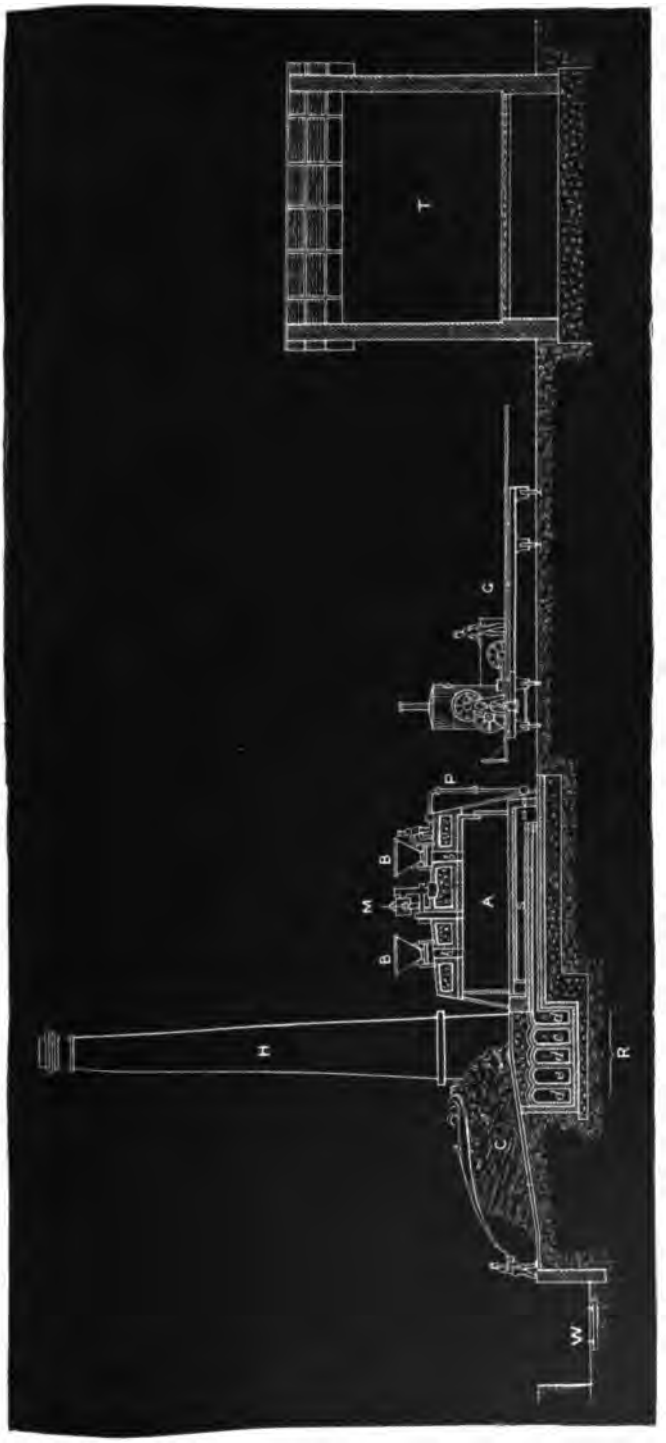
At Pease's West, near Crook, "there are twenty-five ovens, each 23 feet long, 6 feet 6 inches high, and 19½ inches wide, with side and bottom flues, the capacity of each oven being equal to a charge of 4¼ tons of coal. The ovens are connected to each other on the top with 10-inch metal gas pipes, and on these mains is placed a large metal valve box over each oven.

"The gas is drawn from the ovens by one of Beale's patent exhausters capable of drawing 30,000 feet of gas per hour, an engine of 3-horse power being required for working it.

FIG. 100.

"A traversing ram is used for forcing the coke out of the ovens, the fuel used for the steam for this purpose being equal to 28 lbs. per oven per day. The condensing arrangement consists of ten rows of 10-inch metal horizontal pipes in serpentine form, the length of each row being 32 feet, and above these is placed a perforated 4-inch metal pipe for producing water spray.

FIG. 101.



"There are three cylindrical gas scrubbers, each 13 feet 6 inches high and 6 feet 6 inches diameter, connected with each other by 8-inch metal gas pipes. Six tanks are required, each having dimensions of 16 feet diameter by 9 feet 6 inches deep, one for a depositing tank for collecting the ammoniacal liquor and tar, one for saturation, one for decantation, and three for storage. Two steam-pumps are used for pumping the ammoniacal liquor and tar, each being capable of pumping 6000 gallons of liquor per hour."

The following is a description of the Simon-Carvés ovens, with recuperator, as shown in Figs. 100, 101:—A is the coke oven. The coal to be coked is conveyed to the top of the ovens by rails on which the tubs B B run, and by opening a door at the bottom of each tub the coal is discharged into the interior of the ovens by the passages *b b*. The gas evolved from the coal is drawn from the interior of the ovens by means of an exhauster, and passes away through the mains and valves M to the condensers and scrubbers. The tar and ammonia are extracted from the gas by the means generally applied for the same purpose in gas-works. The gas which has been so deprived of the bye-products is brought back to the ovens by the pipes P, and is burnt in the main combustion flue S, and in the other flues which pass under the floors and along the sides of the ovens, the heat thus produced being applied to the ovens externally. R is the recuperator by which the waste heat is used to heat the air for combustion of the scrubbed gases. It is placed outside the brickwork of the ovens, and consists of longitudinal flues *d d' d''* and *e e'*, the smoke and waste products of combustion escaping to the chimney H by *e* and *e'*, while air passes in through *d d' d''* and is heated in them by contact with the hot walls. The flues *e* and *e'* communicate respectively with the chimney and the steam boilers, which can be placed at each end of the row of ovens to utilize further the waste heat of the products of combustion.

The vertically ascending zigzag flues of one-half of the coke ovens are made to communicate with one smoke flue *e'*, and the other half with the smoke flue *e*, the communications being arranged alternately. The cold air supply first enters one end of the flue *d*, situated along the outer side of one smoke flue, and passes at the other end into the second air flue *d'* between the two smoke flues, and thence into *d''*, from which it passes through branches to the several ovens.

The coke is thrust out of the ovens by the steam ram G, which is mounted on a traveller on rails commanding the whole range of ovens. The quenching is done outside the ovens by means of a hose as shown at C, and the coke is afterwards filled into waggons on the rails at W.

H is a chimney proportioned for twenty-five ovens, and at T is shown the house for exhauster, pumps, &c.

Ovens of a similar description are being introduced by C. Otto of Dahlhausen, Lürmann, Semet, and others, as to which there are particulars given in the Journal of the Society of Chemical Industry, July 29, 1883, and Feb. 29, 1884, and in the Journal of the Iron and Steel Institute, 1883 and 1884.*

Figs. 102 to 105 illustrate the coke oven advocated by Dr. C. Otto, of Dahlhausen, in Germany. It is the invention of G. Hoffmann, of Gottesberg, in Silesia, and its essential features consist in the combination of coke ovens with the Siemens regenerator, in order to heat the air serving for the combustion of the gas to as high a degree as possible. Where the gases are passed through a condenser, as is done in all cases where the bye-products of coking are recovered, it is necessary to compensate for the cooling of the

* See "Jour. Iron and Steel Inst.," 1883, pp. 814–815, 828–833, vol. ii. 1884; "Jour. Soc. Chem. Indus.," vols. 1883, 1884, 1885.

Fig. 102.

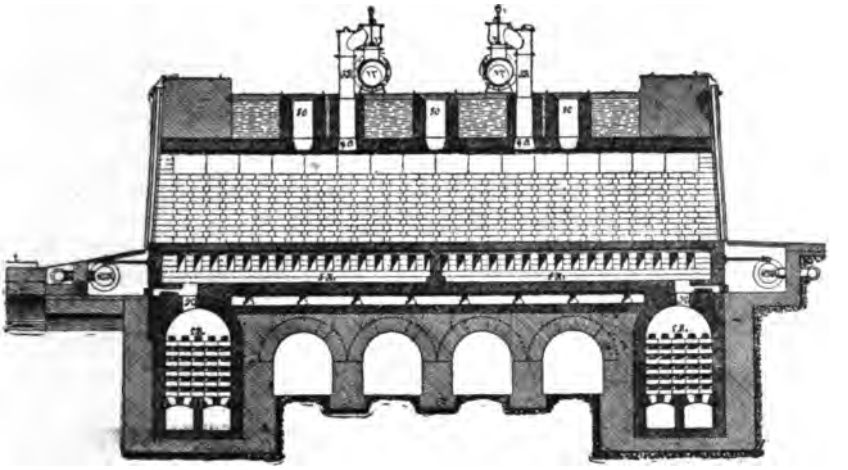
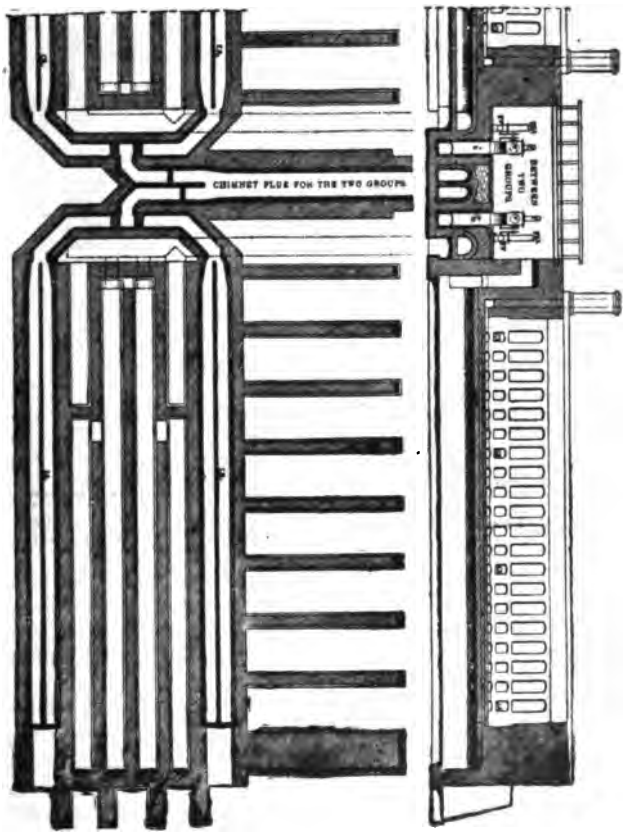


Fig. 103.

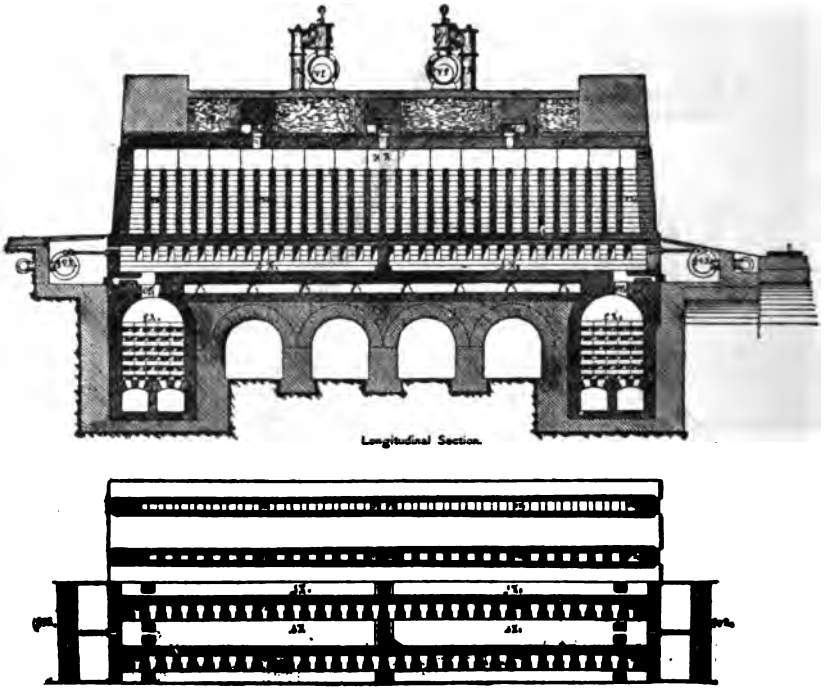


gas by using air at as high a temperature as possible for combustion with the gas. The advantage of a high temperature for coking is now recognized, and this can be obtained only by producing a high temperature of combustion.

Fig. 102 is a vertical section through a coking chamber, and the upper illustration in Fig. 104 shows a similar section through the flue spaces which exist at each side of the coking space. Both figures show the regenerator chambers in transverse section under the battery of ovens. These are also shown very distinctly on the ground plan in Fig. 103, the same figure also showing the arrangement of the reversing valves and chimney flue between two groups of ovens in the elevation.

The side flues are vertical, communicating with one another above by a horizontal flue (Fig. 104), and below with larger horizontal passages which

FIG. 104.



extend under the oven floors, but are divided in the centre so that each half may communicate with a different regenerator.

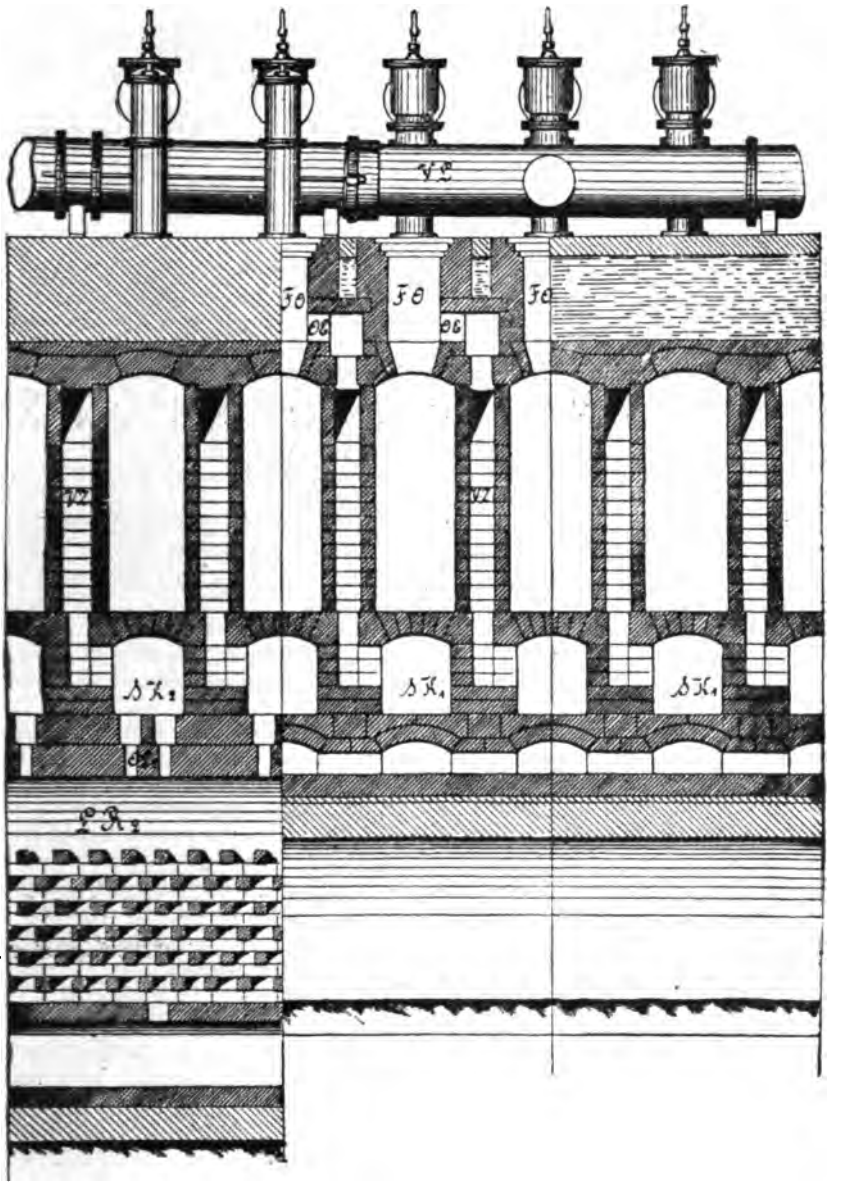
Combustion of the gas and heated air from one regenerator takes place in one-half of these bottom flues, the hot gases and flame rising through the vertical side flues and escaping by the other half bottom flue and the other regenerator. This process is reversed periodically in the manner usual with Siemens furnaces.

The coking chambers have openings at each end for withdrawing the coke, three openings in the roof for filling, and two for the escape of the gases given off in coking. These latter are fitted with pipes and valves communicating with the main gas-pipe or receiver.

Fig. 105 shows a transverse section of the ovens and flues on an enlarged scale.

Dr. Otto stated* that the regenerators for heating the air attain, in the working of these ovens, a temperature of 1800° F., and that, as a consequence, it is found unnecessary to use all the gas given off from the ovens for combustion.

Fig. 105.



In one of the German coking works, out of 24,700 cubic feet of gas produced per coke oven per day, only 17,700 cubic feet were required for combustion. The bottom and side flues become so hot that, with a charge

* "Jour. Iron and Steel Inst.," vol. ii. 1884. p. 520.

of 5 tons 13 cwts. of dry coal, the coking process lasts only 48 hours, and sometimes less.

The following temperatures have been observed:—

In the bottom flue	2200° to 2550° F.
„ side flues	2000 „ 2200
„ regenerator when the current of air was first admitted	1800
One hour afterwards	1330
In the chimney	800 „ 932

The coolers used in conjunction with these ovens have 7.6 square feet of cooling surface per 1,000 cubic feet of gas.

The gas passing out of the coke ovens has been found to show the following temperatures:—

In the rising tube	1200° to 1300° F.
„ receiver or main tube (according to distance from oven)	400 „ 750
Before the coolers	170 „ 250
Beyond „	65 „ 85

The washers used when these temperatures were obtained had 7.8 square feet to every 1,000 cubic feet of gas; but, with a larger supply of water, Dr. Otto stated that the final temperature of the gas could be reduced to 55° F.

With Westphalian coal, the ammonia, reckoned as sulphate of ammonia, recovered amounted to 1 per cent. of the weight of the coal. In the Saarbrücken district the coal yields only 0.7 to 0.8 per cent. of sulphate of ammonia, whilst in Upper Silesia the figure rises to 1.1 to 1.7 per cent.

The yield of tar at one coking works amounted in seven months to an average of 3 per cent. of the weight of coal used.

By the daily treatment of 2 tons 14 cwts. of coal per oven, sufficient waste heat is obtained from every oven to heat 54 square feet of boiler surface, which corresponds (according to Dr. Otto) with an evaporation of 1 pound of water for every pound of coal coked.

In Westphalia, with an ordinary coke oven (without extraction of the bye-products) containing 5 tons 18 cwts. of coal, 80 square feet of boiler surface are heated by the gases, or 1½ lb. of water are evaporated by every pound of coal coked.

The economy of externally fired ovens, in spite of their increased first cost, is undoubted, and of the Coppée form their durability seems to be established. It remains to be seen whether the objections of ironmasters to the coke made in them will give way, or whether improvements will be introduced in working these ovens which will result in the production of the requisite quality of coke. As regards recovery of the bye-products, if the prices obtainable for these fall to a low point, it is questionable if the recovery of such quantities as are yielded from coke ovens would be continued.

THE BLAST FURNACE VALUE OF COKE.

Some very complete and carefully conducted trials on a practical scale in blast furnaces, and also laboratory experiments, to investigate the difference between coke made in beehive ovens and that made in Simon-Carvés ovens, have been carried out by Sir I. Lowthian Bell, and the results are set forth with his accustomed lucidity in the Journal of the Iron and Steel Institute, vol. i. 1885. E. Belani, H. Kutscher (Stahl und Eisen, vol. v. pp. 603–610, 794–801), and Dr. W. Thörner (*ibid.* vol. vi. pp. 71–83) have also made experimental investigations on this subject, and their results are interesting, although not so complete as those of Sir I. Lowthian Bell.

In Bell's trials, in order to eliminate disturbing influences which sometimes affect special trials, "a furnace was selected in good working order,

and its performance was carefully watched when smelting with the mixture of cokes in common use before commencing the Simon-Carvés coke made from the Busty seam at Bearpark Colliery. This precaution was continued during the entire period of the trials, so that the whole experiment should, so far as possible, be conducted under precisely the same conditions." Moreover, a "quantity of Bearpark coke was purchased which was made in beehive ovens, so that the comparison might be more complete than it would otherwise have been, inasmuch as it then became one between the same coal coked in the two different ways."

The total quantity of coke operated on during the trials was 5605 tons, great care having been taken to ensure accurate weighing, and the *consumption* of the various kinds of coke used at Clarence Works during the trials stood in the following relation to each other:—

1.	2.	3.
Mixture from Collieries usually supplying Clarence Works and made in Beehive Ovens.	Bearpark Coke made in Beehive Ovens.	Bearpark Coke made in Simon-Carvés Ovens.
100	101.11	111.11

Comparing the two kinds of Bearpark coke, Nos. 2 and 3, if No. 2 is taken as 100, No. 3 stands at 109.89, showing thus an inferiority of nearly 10 per cent.

The average consumption of No. 1 taken as the standard of comparison was 22½ cwts. per ton for "No. 3 iron," the other two kinds of coke showing a consumption of 22.75 cwts. and 25 cwts. respectively.

"The average temperature of the blast heated in iron stoves was almost exactly 900° F., and that of the escaping gases 575° F."

(1) Analysis of numerous samples of coke taken during the course of the trials gave the following results:—

	No. 1. Clarence Mixture. Beehive Ovens.	No. 2. Bearpark Coke. Beehive Ovens.	No. 3. Bearpark Coke. Simon-Carvés Ovens.
Carbon	89.85	87.60	86.36
Hydrogen	2.00	.25	.51
Oxygen & nitrogen		1.20	1.77
Sulphur	1.06	1.05	1.07
Ash	6.60	8.52	7.94
Water	.49	1.38	2.35
	100.	100.	100.

Sir I. L. Bell remarks that "the heat-giving value in different kinds of coke when burnt in the blast furnace to similar conditions of oxidation depends chiefly, if not entirely, on the quantity of fixed carbon they contain. (2) Viewed by this standard, the *Calorific efficiency* of the three varieties is thus expressed:

No. 1.	No. 2.	No. 2.
100.	97.50	96.11

while the relative values of these cokes according to the quantities consumed to make a given quantity of pig iron are

100.	98.88	90.00"

and he concludes from an examination of these figures that the only way of accounting for the dissimilarity between Nos. 2 and 3 is "by ascribing it to a difference in the extent to which the carbon has been oxidized in the two varieties of coke."

(3) Sir I. L. Bell then institutes a comparison between the beehive and the Simon-Carvés coke in respect of the quantity of heat evolved and beneficially applied in smelting, and of the ratio between the carbonic oxide and carbonic acid in the resulting gases according to his method previously elaborated in his papers* on the manufacture of iron, and in his work on "The Principles of the Manufacture of Iron and Steel." He takes one case, as an example, where the coke consumed per ton of iron corresponded very closely with the beehive coke used in the present trials, when the heat evolved per unit of coke, taking the air at 32° F. (0° C.), was 3653 calories. A very careful series of analyses of the gases made when Simon-Carvés coke was used showed that the oxygen held by them was such that the ratio of carbon as carbonic acid to that as carbonic oxide was as 1 to 3.32, whereas in the specimen case selected with beehive coke the ratio was as 1 to 2.28. The result was that the unit of Simon-Carvés coke afforded only 3094 calories, or 15.3 per cent. less than the beehive coke.

With reference to the loss of heat occasioned by the disappearance of carbonic acid in the gases, he has shown that the quantity of carbonic acid generated per 20 units of iron is a fixed quantity, and that in the reduction and carbonization of Cleveland pig iron 6.57 units of carbon as carbonic acid ought to exist in the gases. In his own practice at Clarence, he has found in the gases 6.52 units per 20 units of iron, while the result when using Simon-Carvés coke was as follows:—

Actual Quantity of Carbon as Carbonic Acid found in the Gases per 20 Units of Iron, from	
Coke in common use at Clarence Works,	Simon-Carvés Coke,
6.52 units	5.12 units

indicating a disappearance of 1.45 units in the latter against only .05 in the former case.

In order to investigate the cause of this greater solution of Simon-Carvés coke in the carbonic acid, specimens were examined microscopically, by ignition apart from access of air, and by exposure to carbonic acid while maintained at a high temperature.

The density of Simon-Carvés coke was superior to that of good beehive coke, a given measure of it being 13.83 per cent. heavier than the latter. Under the microscope, however, it gave indications of being less perfectly freed from bituminous matter than that burnt in the open oven.

The following experiments were then made:—

Representative samples of the different kinds of coke were prepared by mixing specimens which had been taken from the barrows on their way to the furnace during a fortnight. Dried portions of these mixtures finely ground were analysed, and others were exposed for half an hour to the full heat—sufficient to soften porcelain—of a gas blast-furnace, access of air being excluded by placing the crucible containing the sample within a larger one and covering it with charcoal. From the loss of weight in each case, from analysis of the original and residual coke and from the previously ascertained moisture, the following results, all calculated on 100 parts of the original coke, were obtained:—

* "Chemical Phenomena of Iron Smelting."

	Bearpark Coke made in					
	Simon-Carvés Ovens.			Beehive Ovens.		
	Original Coke.	Ignited Coke from 100 of Original Coke.	Expelled by Ignition.	Original Coke.	Ignited Coke from 100 of Original Coke.	Expelled by Ignition.
Carbon . . .	86.36	84.75	1.61	87.60	86.58	1.02
Hydrogen . .	.51	.17	.34	.25	.10	.15
Oxygen and nitrogen	1.77	.89	.88	1.20	.55	.65
Sulphur . . .	1.07	1.02	.05	1.05	.98	.07
Ash . . .	7.94	7.94	—	8.52	8.43	—
Water . . .	2.35	—	2.35	1.38	—	1.38
	100.	94.77	5.23	100.	96.64	3.27

Sir I. L. Bell remarks on these results "if we regard the portions volatilized in these experiments as practically valueless for blast-furnace work, the Simon-Carvés oven shows an inferiority of only 1.96 per cent., or about one-sixth of the actual difference observed in the use of the two kinds of coke. Further and more intense heat might no doubt effect the expulsion of further portions of these substances which have been driven off; at the same time it is open to doubt whether, under any circumstances, they could be entirely volatilized. Their whole amount, however, is not such as to account for the actual difference of results obtained in the blast-furnace, and we may therefore at once turn our attention to the cause of the disappearance of carbonic acid from the gases." This he refers to the fact that different varieties of carbon possess in different degrees the power of withstanding combination with oxygen, as instanced in the readiness with which charcoal is set fire to as compared with coke, and the well-known difficulty with which the diamond can be burnt in oxygen, although the quantities of heat evolved by the combustion of the different forms of carbon are substantially the same. Different varieties of the same form of carbon are understood to behave in a similar way towards the oxygen of carbonic acid, and indeed Sir I. L. Bell's investigations have gone far to establish this as a fact.*

In the present trials, four qualities of coke were made the subjects of the following experiment—they are numbered 1, 2, 3, and 4 in the table following, and Sir I. L. Bell remarks that their values for blast-furnace work may be roughly represented by 100, 95, 92, and 90. In the experiments, "specimens of each weighing 1 gram were finely ground, and in a perfectly dry state were placed separately in four platinum trays. These were introduced alongside each other in a small muffle, which in its turn was placed in the large muffle of a gas furnace. Alongside the former muffle the copper cylinder of a Siemens pyrometer could be laid so as to ascertain by two observations during each trial the temperature within.

"After lighting the furnace and regulating the gas supply, the smaller muffle was placed in position, the door of the larger one was well luted, and a current of carbonic acid was discharged into the interior of the smaller muffle near the roof. The gas supply was maintained as constant in quantity as possible for three hours, during which time, judging from the appearance of the smaller muffle and that of the copper ball, the temperature of the two latter and consequently of the specimens of coke under treatment were as uniform as could be desired."

The following table gives the effects of three hours' exposure to the

* "Chemical Phenomena of Iron Smelting."

carbonic acid at different temperatures. Sir I. L. Bell makes the following important note to Experiment I. "The small amount of loss in Experiment I. may be regarded as due to the mere expulsion of volatile matter from the dried coke, for it has been ascertained that below 1000° F. no CO was found in the gas after passing over the coke; the presence of this substance (CO) being an indication of the reaction $CO_2 + C = 2CO$."

	Cokes from Beehive Ovens.			Cokes from Simon-Carvés Ovens.
	1. So. Brancepeth.	2. Bearpark.	3. Tursdale.	4. Bearpark.
Experiment I.				
Observed temperatures	900° and 1000° F.	900° and 1000° F.	900° and 1000° F.	900° and 1000° F.
Average „	950° F.	950° F.	950° F.	950° F.
Loss of weight on dried coke	1.41 per cent.	1.41 per cent.	1.41 per cent.	2.41 per cent.
Experiment II.				
Observed temperatures	1290° and 1320° F.	1290° and 1320° F.	1290° and 1320°	1290° and 1320°
Average „	1305° F.	1305°	1305°	1305°
Loss of weight on dried coke	4.48 per cent.	7.14 per cent.	7.44 per cent.	12.59 per cent.
Experiment III.				
Observed temperatures	1460° and 1475° F.	1460° and 1475°	1460° and 1475°	1460° and 1475°
Average „	1468° F.	1468°	1468°	1468°
Loss of weight on dried coke	20.04 per cent.	21.04 per cent.	28.28 per cent.	31.90 per cent.
Experiment IV.				
Observed temperatures	1410° and 1570° F.	1410° and 1570°	1410° and 1570°	1410° and 1570°
Average „	1490° F.	1490°	1490°	1490°
Loss of weight on dried coke	41.64 per cent.	46.14 per cent.	64.62 per cent.	62.14 per cent.

Sir I. L. Bell refers the differences in solubility in carbonic acid possessed by varieties of coke to the temperatures at which they have been burnt, and remarks, with reference to the circumstance of a considerable portion of the fixed carbon of the coal being consumed during the process of coking in the open oven and to the heat afforded by its combustion: "It seems highly probable, not only that the direct action of the heat so hardens the coke as to render it less susceptible to the solvent power of carbonic acid, but my own experience is, that to carry this power of resistance to its furthest possible limit, *a quantity of heat is required beyond the capacity of the combustion of the gases*, in the case of Durham coal, to supply it."

Dr. W. Thörner has made numerous experiments on this subject, and his results have been held to show:—

1. That charcoal consists of a large number of more or less regularly arranged cells, which are joined to one another longitudinally. The walls of the cells are readily porous to gases, and are very easily oxidizable.

Coke, on the other hand, contains generally separate unconnected cells or groups of cells, the walls of which are composed of a dense and vitreous mass which does not admit of the passage of gas through it, and is exceedingly difficult to oxidize.

2. That the relatively smaller action in blast-furnace practice of coke as compared with charcoal would be increased were it possible to cause the structure and character of coke generally to more closely resemble that of charcoal, either by the formation of a coke more porous though sufficiently strong, or with greater certainty by rendering the coke substance more easily oxidizable.

The following table gives the results of the examination of several specimens:—

Variety of Fuel.	Colliery.	Ash per Cent.	Specific Gravity.		In 100 Grams Coke.		Volume of 100 Grams of Coke.
			Apparent.	Real.	Cell Space Cubic Centimetres.	Coke Substance Cubic Centimetres.	
1. Retort coke, Osnabrück Gas Works	Pluto	3.8	1.825	0.858	61.6	54.8	116.4
2. Retort coke, Osnabrück Gas Works	Friedrich d. Gr.	7.5	1.811	0.868	60.0	55.2	115.2
3. Compressed coke, Cologne-Müsen Co.		7.7	1.852	0.984	47.6	54.0	101.6
4. Compressed coke, Cologne-Müsen Co.	Morgensonne / Langenbrahm	6.9	1.786	0.969	47.2	56.0	103.2
5. Ordinary Coppée coke, Cologne-Müsen Co..		7.99	1.880	0.926	54.8	53.2	108.0
6. Carlsglück and Planetfeld, Dortmund coalfield		7.8	1.825	0.909	55.2	54.8	110.0
7. Massen, low level	Massen	7.3	1.852	0.890	58.4	54.0	112.4
8. Westhausen, Bodelschwingh		10.6	1.852	0.919	54.8	54.0	108.8
9. Neu-Iserlohn, Langendreer		8.8	1.852	0.874	60.4	54.0	114.4
10. Dannenbaum, Bochum		8.45	1.894	0.890	59.6	52.8	112.4
11. Germania Works, Grevenbrück		7.6	1.909	0.903	58.4	52.4	110.8
12. Heinrichshütte, Au, a. d. Sieg.		7.6	1.887	0.980	49.0	53.0	102.0
13. Meiler coke, Silesia		2.9	1.488	1.046	28.4	67.2	95.6
14. Pine charcoal		2.9	1.626	0.382	200.4	61.6	262.0
15. Oak charcoal		2.45	1.347	0.587	96.2	74.2	170.4
16. Beech charcoal		2.10	1.481	0.594	100.8	67.6	168.4
17. Birch charcoal		1.65	1.351	0.484	132.5	74.0	200.5
18. Anthracite	Piesberg	9.30	1.666	1.572	3.6	60.0	63.6
19. Bituminous coal	Borgloh	8.30	1.323	1.300	1.4	75.6	77.0

In comparing these results, Dr. Thörner observes that amongst the coke samples examined, the meiler coke has the least porosity—28.4 cubic centimetres per 100 grams—and the ordinary retort coke the greatest—61.6 cubic centimetres. The porosity of coke produced in ordinary ovens varied from 54.8 to 59.6 c.c. per 100 grams, a notable exception, however, being the "pressed coke," Nos. 3 and 4, produced on the Lürmann system, in which the porosity is only about 47 c.c. on the same weight of coke.

The porosity of the charcoal varied between 96.2 cubic centimetres and 200.4 cubic centimetres per 100 grams, and it is curious that pine charcoal, the most porous of the varieties examined, possessed the densest charcoal substance.

Microscopical examination of the form and size of the cells and the strength of the cell walls necessitated the use of thin sections, which were photographed under the microscope by Dr. Thörner and engraved for his paper. It was observed that the smallest details of the structure of the original wood were preserved in charcoal, the arrangement of the cells being such that the gaseous products of coking could escape easily, and therefore, in burning the charcoal, oxygen could easily enter. The charcoal substance is not fused by coking, but remains in an easily combustible form, whilst the coke substance is found to be fused into a dense, impenetrable, vitreous mass.

Experiments on the resistance to crushing stress shown by the different varieties of coke were found to give erroneous results when the coke was carefully turned into a cylindrical form. J. Fulton,* in his investigations on the physical properties of coke, relied greatly on the indications of hardness given by resistance to crushing stress, but Dr. Thörner remarks that the use of cubes, as employed by Fulton in his experiments, is open to the objection that it is almost impossible to obtain from such a brittle material cubes of exactly the same size, and that he found that cubes pro-

* The Physical Properties of Coke, &c., "Trans. Amer. Inst. M. Eng.," 1883.

duced were never free from slight cracks. It was, however, shown by the experiments with cylindrical test pieces that, as a general rule, the crushing strain of coke was from 0.97 to 1.73 kilograms per square millimetre of surface, but, as the results agreed very badly, a further series of tests was made, in which the coke was cut to pieces of about 10 millimetres diameter, surrounded by an iron jacket and put under a piston, by means of which it was subjected to a crushing stress. The volume to which the coke was compressed by successive increasing loads was noted after each load, and the results showed that the relative strength or compressibility was, as a rule, directly dependent on the porosity, both in the case of charcoal and in that of coke.

In following Sir I. L. Bell's line of investigation into the relative resistance of coke and charcoal to carbonic acid, Dr. Thörner subjected the specimens to a preliminary heating at a white heat in a current of hydrogen, and found a considerable loss in some cases.

The following numbers show the decrease in weight per cent.:—

No.	2. Retort coke	0.25
„	3. Compressed coke	1.40
„	4. Compressed coke	1.15
„	5. Coppée coke	1.13
„	6. Carlsglück, &c., coke	1.55
„	7. Maassen coke	1.70
„	8. Westhausen coke	1.70
„	10. Dannenbaum coke	0.75
„	13. Meiler coke	29.70
„	14. Pine charcoal	17.90
„	15. Oak charcoal	13.20
„	16. Beech charcoal	11.80
„	17. Birch charcoal	13.20

The above considerable loss in the case of meiler coke and others is explained as being due to the escape of hydrocarbons and not to evolution of water.

In examining the action of carbonic acid and of air on the specimens, 1 gram of each sample of coke and 0.5 gram of each variety of charcoal were placed in a platinum tray, and heated in currents of air or carbonic acid for different periods with the following results:—

Fuel.	Heated in Carbonic Acid (Loss per Cent.)			Heated in Air or 10 Minutes, 4.5 Litres Air being used. (Loss per Cent.)
	For 15 Minutes. 500 c.c. CO_2 used.	For 30 Minutes. 1 Litre CO_2 used.	For 2½ Hour 5 Litres CO_2 used.	
1. Retort coke	—	10.6	27.2	46.8
2. Retort coke	—	11.8	38.6	45.0
3. Compressed coke	—	13.8	38.0	51.0
4. Compressed coke	—	8.4	27.2	48.9
5. Coppée coke	—	8.7	27.5	50.1
6. Carlsglück coke	—	8.3	29.3	54.4
7. Maassen coke	—	8.0	29.3	51.5
8. Westhausen coke	—	9.5	26.2	52.9
9. Neu Iserlohn coke	—	12.2	34.0	46.8
10. Dannenbaum coke	—	6.8	22.6	57.1
11. Germaniahütte coke	—	8.9	32.0	52.1
12. Heinrichshütte coke	—	6.9	24.3	52.5
13. Meiler coke	—	45.6	100.0	87.7
14. Pine charcoal	61.1	96.3	—	100.0
15. Oak charcoal	48.8	85.0	—	78.6
16. Beech charcoal	60.4	95.0	—	80.3
17. Birch charcoal	68.0	95.0	—	100.0
18. Anthracite	—	—	—	45.4
19. Bituminous coal	—	—	—	74.4

Localities,	Weight in Grams in 1 Inch Cube.		Weight in lbs. in 1 Foot Cube.		Proportion per Cent.		Resistance to Compression per Cubic Inch (½ of the Extreme Resistance).	Height of Charge in Blast Furnace supported without Crushing.	Ratio of Cellular Space.	Hardness.	Specific Gravity.	Chemical Analyses.						
	Dry.	Moist.	Dry.	Moist.	Coke.	Cells.						Fixed Carbon.	Moisture.	Ash.	Sulphur.	Phosphorus.	Volatile Matter.	
								Feet.										
Connellsville . .	12.46	20.25	47.47	77.15	61.53	38.47	284	114	1	3.50	1.500	89.57	0.30	9.11	0.82	0.014	0.460	Closed oven 72 hours' coking
East Virginia . .	13.76	21.19	52.54	81.56	64.32	35.67	258	103	1	3.15	—	92.18	0.11	6.68	0.618	0.027	0.350	
Broad Top . .	11.76	20.18	44.81	76.88	58.27	41.73	240	96	1	3.35	1.342	89.28	—	8.66	1.06	—	—	Closed oven
Clearfield . .	14.79	19.86	56.35	76.69	74.43	25.57	319	128	1	3.60	1.560	89.86	0.54	9.41	—	—	0.667	
Cumberland . .	12.76	21.63	48.61	82.41	58.99	41.01	215	86	1½	3.00	1.750	—	—	—	—	—	—	
Alabama . .	13.30	18.29	50.70	69.01	73.77	26.23	225	87	1	3.50	1.493	—	—	—	—	—	—	
Illinois . . .	11.06	17.09	43.02	65.09	63.79	36.21	180	70	1	3.20	1.215	89.77	0.12	9.58	0.93	0.033	—	
Cambria Iron Co., Bennington .	13.36	19.74	50.90	75.20	67.68	32.32	281	112	1	—	—	—	—	—	—	—	—	Open oven
Broad Top . .	12.00	19.59	45.72	74.53	61.25	38.75	220	88	1	—	—	—	—	—	—	—	—	Open oven
Connellsville . .	14.02	20.95	53.41	79.81	62.92	33.08	249	114	1	—	—	—	—	—	—	—	—	Closed oven 48 hours' coking
Cambria Iron Co., Johnstown .	11.50	20.06	43.82	76.41	56.80	43.20	245	99	111	—	—	—	—	—	—	—	—	Belgian oven

The preceding table gives the results of investigations into the physical and chemical properties of coke by John Fulton: "Trans. Amer. Inst. M.E. 1883."

Gases from Coke-ovens.—M. Ebelmen made an interesting series of experiments to determine the composition of the gas which escapes from coke-ovens.

Fig. 106.

The coke-ovens of Seraing, constructed as shown in the accompanying drawings, were the subject of the experiments.

Fig. 106 shows a vertical section through the ovens, and the boiler which is set above them, and a longitudinal elevation of a part of the range.

Fig. 107.

Fig. 107 is a section according to the line *A B* on Fig. 106, and a horizontal projection of the remainder.

Fig. 108.

Fig. 109.

Fig. 110.

Fig. 108 shows a vertical section through the boiler.

Fig. 109, an end elevation.

Fig. 110, a section according to the line *C D* in Fig. 106.

The ovens are cylindrical, with a door at each end. There are three chimneys; one in the centre of the range, and another at each end. The dimensions of the central one are equal to those of the other two, but the three are not employed at the same time. It is found that the dimensions of these chimneys are of great importance, as they regulate the admission of air into the ovens, and the rapidity of the process of coking. Eight ovens discharge their products of combustion into the central chimney, and the hot gases passing under a steam boiler raise sufficient steam for an engine of 80-horse power which drives the blast furnaces of the iron-works. The coal employed at these works belongs to the caking class, and yields by direct analysis:

Coke	Carbon	78
	Ash	2
Volatile matter		20
		100

The composition of the coal approaches that of Rochebelle, which consists, according to Regnault, of:

Carbon	89.27
Hydrogen	4.85
Nitrogen and oxygen	4.47
Ash	1.41
	100.00

The coking lasts about twenty-four hours, and the yield of coke in the ovens averages 67 per cent. M. Ebelmen collected the gas at three different periods, and analysed it with the following results:—

	After 2 Hours.	After 7½ Hours.	After 14 Hours.	Mean.
Carbonic acid	10.13	9.60	13.06	10.93
Carburetted hydrogen	1.44	1.66	0.40	1.17
Hydrogen	6.28	3.67	1.10	3.68
Carbonic oxide	4.17	3.91	2.19	3.42
Nitrogen	77.98	81.16	83.25	80.80
	100.00	100.00	100.00	100.00
Oxygen to 100 vols. of nitrogen	15.7	14.2	17.0	15.6

The relation, then, between the coal and escaping gas is as follows:—

	Coal.		Coke left.		Gas.
Carbon	89.27	...	67.00	...	23.68
Hydrogen	4.85	...	—	...	4.85
Oxygen and nitrogen	4.47	...	—	...	4.47
Ash	1.41	...	—	...	—
	100.00	=	67.00	+	33.00

The relation of the carbon to the hydrogen is as 23.68 : 4.85, or 1 to 0.205 by weight; while the relation in the gas, according to the mean of the above analyses, is 1 to .064 by weight; from which we may infer that ⅔ of the hydrogen of the coal is consumed during the carbonization. There is only a very small quantity of tar produced in consequence of the high temperature of the ovens; this also accounts for the small quantity of carburetted hydrogen found among the permanent gases.

The mean quantity of oxygen, 15.63 for 100 of nitrogen, shows that 10.63 must have combined with hydrogen and passed off as aqueous vapour, as 26.26 parts must have been introduced for every 100 of nitrogen; but

much stress cannot be laid on this inference, as the amount of air admitted to the ovens is not stated.

These data further prove, that $\frac{2}{3}$ of the whole heat which is lost is sensible, and of course necessitates that it should be rendered available on the spot, as it cannot be conveyed to any great distance, more especially as the gases do not contain much combustible matter. It is evident that the heat necessary for coking is produced partly by the combustion of the products of distillation, and partly by the burning of a portion of the residual coke.

The cost of making coke in this country used to be about 1*s.* 2*d.* per ton; but it is now increased slightly above that figure in consequence of higher rates of wages.

	s.	*d.*		
Charging and burning coke, with all attendance required, including filling waggons	0	10	per ton	coke
Filling ovens with coal	0	2	,,	,,
Wear and tear of ovens	0	2	,,	,,
Total cost	1	2	,,	,,

Mr. Dixon, of Crook, however, gives the cost of labour at ordinary beehive ovens at 1*s.* 0.65*d.* per ton of coke. Wear and tear of ovens is not included in this.

TAR FROM COKE OVENS.

The preparation of coke is necessarily a process of destructive distillation, and consequently involves the formation of tar. Increased economy in the manufacture of coke has led to methods which include the collection of the tar (pp. 180–192.).

The general properties of a coke-oven tar must obviously depend on the temperature, when the coal distilled is the same. It is in fact found that such a tar as that from the Jameson coke ovens, where the heat at the point of destructive distillation is extremely low, is very rich in paraffins and kreasote phenoids—phenol and the aromatic series in general and non-volatile products being absent in quantity. Tar from the Simon-Carvés ovens, on the other hand, is the result of a very high temperature, and chiefly remarkable for the enormous amounts it contains of naphthalene, anthracene, and non-volatile products—the paraffin series being almost entirely absent. The tar from blast furnaces is of intermediate quality.

It is chiefly to Watson Smith* that we are indebted for the analytical examination of these tars. The following is a summary of his results.

Jameson Tar.—The average specific gravity is 0.97. Naphthalene and anthracene, though carefully tested for, could not be found. The oil was not fluorescent. The following is an example of the fractionations :—

Fraction.	Temperature.	Specific Gravity.	Volume.
A.	Below 150°	.829	0.8
B.	150°–230°	.892	9.2
C.	230°–300°	.953	36.0
D.	300°–350°	.970	6.7
E.	350°–400°	.971	19.0
F.	Above 400° oil solid on cooling	—	9.85
G.	Paraffin soft scale	—	5.45
H.	Pitch	—	10.00
Loss	—	—	2.00
			100.00

* "Jour. Soc. Chem. Ind.," 1883, p. 495; "Jour. Iron and Steel Inst." 1884, No. 2 pp. 486–516.

A little toluene and xylene were found in fraction A; B perhaps contained a small quantity of phenols, which were accompanied by a burning oil of bad quality; C was a light yellow oil, not very suitable for burning; D had too little body for a lubricant; E was a fairly good lubricant; F and G yielded a satisfactory amount of scale. The pitch gave off ammonia. Closer examination of the "phenols" of this tar showed the presence of much sulphuretted hydrogen, the oil itself consisting chiefly of kreasote phenoids, and not of phenols.

It is noteworthy that, in the treatment of these tars, Smith did not employ steam in the distillations.

Blast-furnace Tar.—The samples were obtained from Gartsherrie (Scotland), where a process is in operation for recovering ammonia as well as tar from blast-furnace gases. The volume of the gases is about 120,000 cubic feet per ton of coal. The tar may be regarded as in fact a coke tar.

The specific gravity of the tar was .954. One of the heavier fractions showed green fluorescence. The following results were obtained on distillation:—

Temperature.	Specific Gravity.	Percentage Volume.
Below 230°	Water 1.007 Oil .899	30.60 2.91
230°–300°	.971	6.97
300° until solid	.994	13.02
Soft scale	.987	16.75

Coke, 21.4 per cent.; loss, 5.5 per cent.

Anthracene was absent. None of the oils were found very suitable for lubricating purposes or for burning in lamps. The phenolic portion, dissolved out by soda, contained a little ordinary phenol, rather more creasol, and abundance of phenoids; coke, about 5½ per cent.

Simon-Carvés Tar.—Specific gravity 1.106. In general appearance this tar closely resembles that from gas retorts. Naphthas, benzene, and carbolic acid are present in small quantity only, the characteristic feature of the tar being its large percentage of naphthalene and anthracene. Watson Smith gives the following results:—

Temperature.	Percentage Volume.	Remarks.
Below 100°	6.2	Water.
„ 120°	1.6	—
„ 210°	2.9	—
„ 220°	1.3	Chiefly naphthalene.
„ 230°	0.5	
„ 300°	18.6	Naphthalene, anthracene.
Above 300°	34.2	Crude anthracene.

Half-coked pitch, about 33 per cent.; loss, about 1 per cent.

Most of the "gas-producers" yield small quantities of tar, the nature of which lies well within the range above described.

Distillation of Peat.—A patent was obtained in the year 1849 by Mr. Rees Reece for the production of gas, paraffin, oils, pyroligneous acid, pyroxylic spirit, and ammonia, from peat, by which the bog lands of Ireland, hitherto a reproach, were to be converted into a mine of wealth to the country.* The process, as patented by Mr. Reece, consists in burning peat in a blast furnace of similar construction to the iron blast furnaces, only closed at the top, and furnished with apparatus for carrying away and condensing the volatile

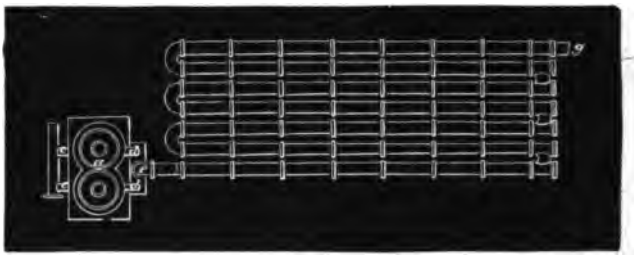
* On account of its great historical interest, a somewhat minute description of this process has been retained in this edition of the work.

products of distillation. Fig. 111 shows a sectional elevation of the blast furnace, and Fig. 112 a plan of the pair of furnaces intended to work together with the pipes for condensing the products.

Fig. 111.

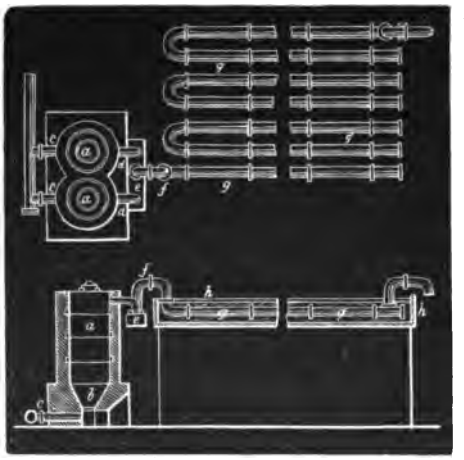
The drawings are taken from Mr. Reece's original specification. The furnaces and condensing apparatus, subsequently erected on the Bog of Allen,

Fig. 112.



near Athy, were somewhat differently constructed; the furnaces had more the shape of iron blast furnaces, were built of brick, 10 feet in diameter at the widest part, and encased in sheet iron, the mouths being furnished with a double cone, similar to that shown in Fig. 136, page 229. The condensers were not surrounded by water, but were upright, connected together two and two at the top, and terminating at the lower open extremities in a metal box, with a diaphragm, which served as a recipient for the semi-solid tar, and, at the same time, as a valve for preventing the escape of the gases. It was calculated that 12,000 feet of surface would be required to condense the products from 100 tons of peat. Scrubbers were erected at the end of the very extensive series of condensing pipes, in which the escaping gases were well washed with water, and the last trace of ammonia removed.

Fig. 113.



The furnaces being charged with air-dried peat, ignited at the bottom, and closed, the blast was applied, furnishing 3000 cubic feet of air per minute, the amount required for the distillation of 100 tons of peat in the twenty-four hours. The heat from the combustion of the peat in the lower part of the furnace was thus employed to distil the upper layers; the products

of combustion, with the proceeds of the distillation, being forced forward by the blast to the condensers.

The crude products of the distillation were tar, water, and gas, the ashes of the peat fluxing, according to Mr. Reece, and flowing out as slag. The two former, the tar and water, were collected in tanks connected with the condensers, while the gas passed on through flues to the various boilers, evaporating pans, tar-stills, &c., where it was employed as fuel. From 100 tons of peat, 6 million cubic feet of mixed gases were said to be obtained, consisting of hydrocarbons, free hydrogen, and carbonic oxide, some nitrogen and carbonic acid; it was calculated that 2 millions of cubic feet would be sufficient for carrying on all the operations connected with the manufacture of the products, leaving 4 millions to be applied to other purposes, such as burning lime, making bricks or glass, for which the gas, on account of the absence of sulphur, was said to be peculiarly well adapted.

The water, which could be easily separated from the tar which swims on its surface, amounted to from 10,000 to 12,000 gallons from 100 tons of peat. The water contained wood naphtha, or pyroxylic spirit, with acetate and carbonate of ammonia in solution. Lime was added to it in the proportion of 6 cwt. to 10,000 gallons, and the ammonia and naphtha in the rough liquor, were separated by a modification of Coffee's still. The mixed vapours of ammonia and naphtha, being separated from the dilute solution of acetate of lime, were passed through a closed vessel containing dilute sulphuric acid, which converted the ammonia into sulphate, whilst the naphtha was again passed through a similar apparatus, or "rectified at once by blowing steam into it in a close safe, with a set of cups attached." The acetate of lime, or "spent-wash," from the distilling apparatus, was boiled down in large evaporating pans of cast-iron, or boiler-plate, until the solution contained about 10 per cent. of acetic acid. The crude acetate was then decomposed by sulphuric acid, and again distilled, the free acid recombined with lime, and boiled down in leaden pans to the point of crystallization.

The tar from 100 tons of peat was said to contain from 300 to 350 lbs. of paraffin, a mixture of hydrocarbons first discovered by Reichenbach in the tar of wood. This was the most valuable product from the distillation, and in order to separate it from the oils in the tar which accompanied it, the latter was melted, and while at a temperature of 38° C. (100° F.), 20 gallons of sulphuric acid were added, and well agitated for about twenty minutes. Much of the tar was thus charred, and rendered heavier than water, and this portion, with the basic oils, sank on the addition of hot water, while the paraffin and lighter oils came to the surface. These were distilled either by direct furnace heat or by superheated steam, and the more volatile portions, about one-half of the whole, collected apart from the heavier oils and paraffin. This latter portion was allowed to cool, when the paraffin crystallised in flakes which floated in a liquid oil; this was strained, and the crystalline mass pressed to remove the oil. The paraffin was subsequently purified by a repetition of the same treatment, and was then in a fit state for the market. The oils which accompany the paraffin had, unfortunately, a very fœtid odour, which rendered them useless in their crude condition; they had, therefore, to be treated with caustic soda, or lime, and subsequently with oil of vitriol, before they could be applied to lubricating or other purposes.

Messrs. Kane and Sullivan submitted the whole of the products resulting from the distillation of different varieties of peat, both in close vessels and by means of a blast of air, to a strict examination on a small scale, with a view to test, in the laboratory, as far as possible, the probable economic value of the process. The chemical nature of the specimens employed in this investigation will be found on pp. 15–20, under the head of "Peat or Turf." Their results, as far as the nature of the products and the quantities in which

they are obtained are concerned, corroborate generally those of Reece; but they were unable to separate and purify these products by the methods he employed; nor could they obtain combustible gas at all in conducting the distillation with a blast of air, although the quantity of air admitted was varied in different experiments. It was also found very difficult to condense the products in the latter case, and to regulate the blast so as to obtain the products in any quantity; if too little force of blast was employed, a very long time was required to consume the peat, and a large produce of tar, some light carburetted hydrogen, but chiefly carbonic acid gases, were obtained; if too much air was forced through the furnace, hardly any tar or liquid products were condensed, while a considerable amount of carbonic oxide was produced. It was inferred from these facts, that, if it were necessary to produce carbonic oxide for the manufacture, no tar would be obtained; whilst if the operation were conducted sufficiently slowly to form tar, it would be found impossible to obtain carbonic oxide. In every case of imperfect combustion, the aqueous liquid was acid at the end of the operation; whilst in closed cylinders, and when the blast was properly regulated, the alkaline reaction increased with the temperature and rapidity of the distillation. In no case was the temperature in the apparatus very high, and always quite inadequate to flux a substance composed of the ingredients contained in ordinary peat ashes, although Mr. Reece obtained a fused slag as the residue in his process. With a proper regulation of the blast, it was found that the condensable products increased with the length of time occupied in working off the charge, and large quantities of ulmin-like resinous bodies were obtained, which it was apprehended would be liable to clog the condensing apparatus. On the whole, however, with a careful regulation of the blast, very nearly the same results were obtained with this apparatus as in the close vessels, as will be seen by the following Tables, in which the results are given, and compared with those obtained by Mr. Reece. The elementary composition of the specimens experimented upon will be found at pages 15 and 20.

TABLE I.—*Representing the Percentage of Tar, Water, Charcoal, and Gas, obtained from the Specimens of Peat subjected to Distillation.*

Number of Specimen.	Corresponding Number on Table, p. 16.	Locality from whence Obtained.	Water.	Tar.	Charcoal.	Gas.
1	2 and 3	Mount Lucas Bog, Phillipstown	23.600	2.000	37.500	36.900
2	7	Light Surface Peat from the Wood of Allen	32.273	3.577	39.132	25.018
3	9	Black Compact Peat, Wood of Allen	38.102	2.767	32.642	26.489
4	4	Tichnevin	33.628	2.916	31.110	32.346
5	Ditto	Ditto, distilled with retort heated to redness	32.098	2.344	23.437	42.121
6	22	Upper Shannon	38.127	4.417	21.763	35.693
7	24	Upper Shannon	21.819	1.462	18 973	57.746
			219.647	19.483	204.557	256.313
			31.378	2.787	29.222	36.616

TABLE II.—*Representing the Percentage of the Principal Commercial Products obtained from the Distillation of Peat, with the Corresponding Values given by Mr. Rees Reece.*

Number of Specimen.	Ammonia.			Acetic Acid.			Pyroxylic Spirit or Naphtha.	Paraffin.	Volatile Oils.	Fixed Oils.
	Ammonia (NH_3).	Corresponding Quantity of Sulphate of	Quantity of Sulphate of, obtained by Mr. Reece.	Acetic Acid. ($C_4H_3O_3 + HO$).	Corresponding Quantity of Acetate of Lime.	Quantity of Acetate of Lime according to Mr. Reece.				
1. Phillipstown. Table, p. 16 .	0.302	1.171	100 tons of peat yield 1 ton of sulphate of ammonia, = 1.00 per cent.	0.076	0.111	100 tons of peat yield 14 cwt. of grey acetate of lime, = 0.70 per cent.	0.092	0.024	0.684	0.469
2. Light Surface Peat—Wood of Allen. Table, p. 16 . .	0.187	0.725		0.206	0.302		0.171	0.179	0.721	0.760
3. Wood of Allen, dense. Table, p. 16	0.393	1.524		0.286	0.419		0.197	0.075	0.571	0.565
4. Tichnevin. Table, p. 16. .	0.210	0.814		0.196	0.287		0.147	0.170	1.262	0.617
5. Ditto distilled at full red heat .	0.195	0.756		0.208	0.305		0.161	0.196	0.816	0.493
6. Light Surface Peat—Shannon. Table, p. 16. . . .	0.404	1.567		0.205	0.299		0.132	0.181	0.829	0.680
7. Shannon, dense. Table, p. 16.	0 181	0.702		0.161	0.236		0.119	0.112	0.647	0.266
7)	1.872	7.259		1.338	1.959		1.019	0.937	5.530	3.850
Average . . .	0.268	1.037		0.191	0.280		0.146	0.134	0.790	0.550
							Reece: 100 tons of peat yield 52 gallons, at 8 lbs. to the gallon, = 0.185 per cent.	Reece:—100 tons of peat yield 300 to 350 lbs. = 0.133 to 0.156 per cent.	According to Reece, 100 tons of peat yield about 200 gallons of oil, which, at 9 lbs. to the gallon, = 1800 lbs. = 0.803 per cent.	According to Reece, 100 tons of peat yield 98.6 gallons of oil, which, at 9 lbs. to the gallon, is = 887.4 lbs. = 0.396 per cent.

TABLE III.—*Representing the Proportions of Water, Tar, Ash, and Gas, obtained by the Distillation of Peat in a Blast of Air, with the Corresponding Results obtained with a Closed Retort.*

	Corresponding No. in Table, p. 16.	Locality of Specimen.	Water.		Tar.		Ash.		Gas.
			In Blast of Air.	In Closed Retort.	In Blast of Air.	In Closed Retort.	In Blast of Air.	In Closed Retort.	In Blast of Air.
1	7	Light Surface Peat —Wood of Allen .	31.678	32.273	2 510	3.577	2.493	2.745	63.319
2	9	Dense Peat—Wood of Allen	30.663	38.102	2.395	2.767	7.226	7.898	59.716
3	24	Shannon—No. 4 .	29.818	21.819	2.270	1.462	2.871	2.976	65.041

TABLE IV.—*Representing the Percentage of Ammonia, Acetic Acid, Pyroxylic Spirit, Paraffin, and Oils obtained by the Distillation of Peat in a Blast of Air, and the Corresponding Results obtained with a Closed Retort.*

Number.	Corresponding No. in Table, p. 16.	Locality of Specimen.	Ammonia.		Acetic Acid.		Pyroxylic Spirit.		Paraffin.		Oils.	
			In a Blast of Air.	In Closed Retort.	In a Blast of Air.	In Closed Retort.	In a Blast of Air.	In Closed Retort.	In a Blast of Air.	In Closed Retort.	In a Blast of Air.	In Closed Retort.
1	7	Light Surface Peat—Wood of Allen . .	0.322	0.187	0.179	0.206	0.158	0.171	0.169	0.179	1.220	1 481
2	9	Dense Peat—Wood of Allen . . .	0.344	0.393	0.268	0.286	0.156	0.197	0.086	0.075	0.946	1 136
3	24	Shannon—No. 4. .	0.194	0.181	0.174	0.161	0.106	0.119	0.119	0.112	1.012	0.913
		3)	860	761	621	653	420	487	374	366	3.178	3.530
		Average	287	254	207	218	140	162	125	122	1.059	1.177

The amount of paraffin, according to these experiments, obtained from 1 ton of peat does not exceed 2½ lbs. An analysis of it is subjoined :—

	Reece.		Reichenbach.
Carbon . . .	84.45	...	85.22
Hydrogen . . .	14.83	...	14.78
Oxygen, or loss . .	.72	...	—
	100.00	...	100.00

indicating a close approximation to that of the paraffin from beech-wood tar.

ARTIFICIAL OR PATENT FUEL.

It is obvious that the invention of any new or artificial fuel, is in itself an impossibility, unless the term is used to imply an adaptation of those natural fuels which have been rendered unfit for use by too great subdivision. It is in this sense that the term is here employed.

In some parts of Norway, where large quantities of saw-dust accumulate at the mills, 18 to 24 parts by bulk have been mixed with 8 parts of clay and ⅛ of tar, and formed into bricks for boiler fires.

Attempts have been made to employ small-wood refuse, shavings, saw-dust, tan, charcoal- and coal-dust, and similar substances for the production of gaseous fuel, in the manner which will be described below, but they do not appear to have been attended with invariable success. The substances

chiefly employed in the manufacture of artificial fuel are charcoal-dust, peat or turf, small-coal, slack or brees, with refuse fat, tar and pitch.

Refuse charcoal, peat, and other vegetable substances, have been charred with tar and pitch, and submitted to pressure, as described at pages 112–114.

Charcoal-dust is also stated to have been economized in French iron-furnaces by allowing the blast to carry a certain portion of it into the body of the furnace.

A patent was taken out many years ago, in the Austrian States, by Swozil, for converting turf into a hard substance, resembling coal, by mixing certain organic liquids with it, which gave rise to a species of putrefactive fermentation, after which it burned with remarkable ease and considerable heating power.

Mr. Hill distils dry peat, and collects the pyroligneous spirit and tar. The tar is converted into pitch, which he mixes, while hot, with peat charcoal, and thus renders a very bulky, and, for many purposes, valueless article, one of considerable importance.

Weschniakoff many years ago manufactured from a mixture of small coal and refuse animal fat a substance which he called "carboleine." In this process, an excess of fat and small coal were well mixed together and made into the form of bricks, and the mixture submitted to pressure between coarse hair-cloths.

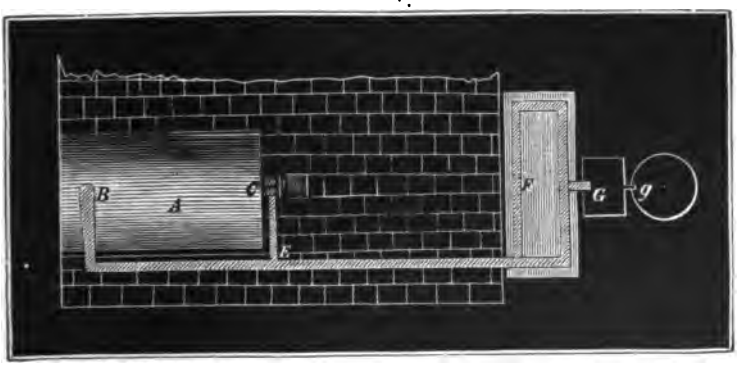
This substance, as analysed by Kaiser, was composed of:

Small coal	84
Fat	8
Ash	8
	100

The specimen analysed by Kaiser on Berthier's plan was found to be inferior in heating-power to good English coal, owing probably to the inferiority of the coal employed in its production. Being in the form of bricks, however, it had the advantage of occupying but a small space when packed in steam-vessels.

Wylam's Patent Fuel.—Another process, of a much more extensive and important nature, has been carried out on a large scale by Mr. Wylam. The substances employed in the manufacture are small coal and pitch, which are moulded together by pressure into bricks. As this manufacture consists, how-

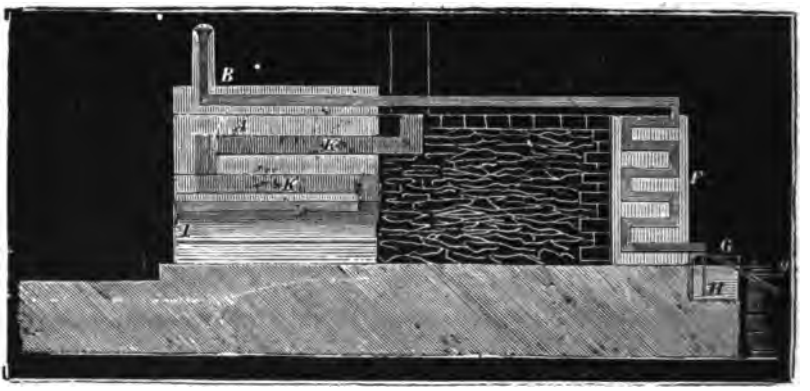
FIG. 114.



ever, of several distinct branches, it will be better to consider them separately. The first operation is the separation of coal-tar by distillation into naphtha, dead oil and pitch. The pitch is subsequently mixed with small coals, and

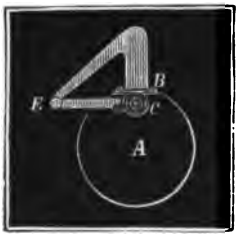
then moulded. The naphtha is rectified and sold as such, while the dead oil is converted into ivory-black or employed for preserving timber. The tar is steamed to facilitate the separation of the naphtha. The process of distillation is conducted by exposing the tar and water to the heat of a common fire in a large iron retort, *A*, Fig. 114. Two pipes, *B* and *C*, uniting at *E*, convey the volatile products from the retort. During the first stage of the distillation, the pipe *C* is closed by a valve at *d*, and the naphtha and water escape through the swan-neck shaped pipe *B*, which is carried about 3 feet above the retort, to prevent any dead oil passing off at the same time, during any sudden ebullition of the contents of the retort. The pipe then passes through a condenser *F*, kept cool by a stream of water, and discharges the naphtha and water into the vessel *G*. The naphtha floats on the top, and flows off in a continuous stream at *g*, while the water syphons itself off by the syphon *H*, Fig. 115, as it accumulates. As soon as all the naphtha has

Fig. 115.



passed over, the pipe *c* is opened, and more heat applied, until the distillation of the *dead oil* is complete. The pitch which remains behind is ultimately drawn out by an opening at the lower end of the retort, into shallow stone coolers. *I* indicates the position of the fire-places, and *K K* the flues for heating the retort. Fig. 116 shows an end view of the swan-neck of the retort.

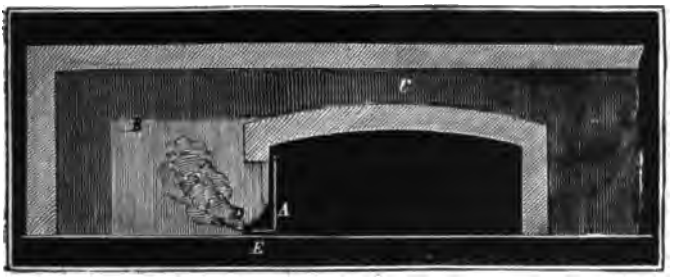
Fig. 116.



The *naphtha* is redistilled by steam, and the *dead oil* obtained as the second product of the distillation of the coal-tar, is sold for anthracene extraction, and for preserving timber from decay when exposed to damp and water, as in railway sleepers, piers and docks. It is also employed, after the said extraction, as a solvent for pitch, in which case it makes a valuable varnish, for coating wood and iron-work exposed to the weather, and lastly, for the manufacture of a very superior *lamp-black*. The arrangements for making the lamp-black are very simple. The dead oil, which is kept in a large reservoir, is heated by means of steam, to render it more fluid, so that it may flow through the pipe *A*, Fig. 117, more easily, and ultimately arrive at *D*. It is ignited at this point, and the lamp-black which is produced is deposited in long galleries, into which it passes through the flue *C*. The large chamber *B* is constructed with the view of preventing occasional explosions extending into the galleries. Fig. 118 shows the end-view of the burners *E E*.

The pitch after having become hard, is ground under edge-stones, and mixed with small coal in the proportion of 1 to 4. The mixture of coal and pitch is carried up into a large hopper, from which it gradually passes into

FIG. 117.



the receivers *M M M*, Fig. 119. At the bottom of these receivers, a pair of plain rollers *O*, Fig. 120, are kept in motion by the shaft *N*, Fig. 119, and by

FIG. 118.

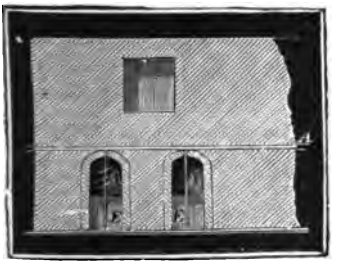
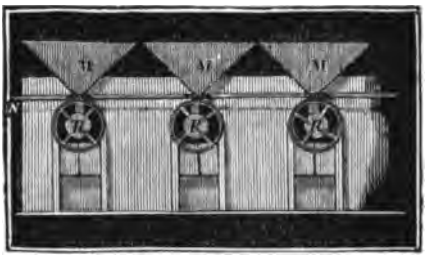


FIG. 119.



this simple contrivance, a regular supply is thrown into the retort *R*. An Archimedean screw *Q*, Fig. 120, is also made to revolve inside the retort, by the shaft *N*. The retort is maintained at a dull red heat by the hot air in the flue *T*, and the fuel passes through the whole length of the retort, which is some 15 feet long, in about three minutes. The mass of coal and pitch is discharged at the opposite end of the retort in a pasty state, and carried by an endless chain into the receiver *S*, Fig. 121, where it is kept in motion by the arms *r r*, so as to prevent it hardening into lumps. From this cylinder or receiver it runs into large moulds, where it is subjected to a heavy pressure in the following manner. *A* represents a moveable oval table, upon which the moulds *B B* are fixed, *S* the vessel which receives the fuel paste, *u* and *x* two cylinders similar to those of a steam-engine, but worked by water, *v y* the pistons, to which two rams are attached, each having six arms that fit accurately the moulds *B B*, and *z* is a lever, worked

FIG. 120.

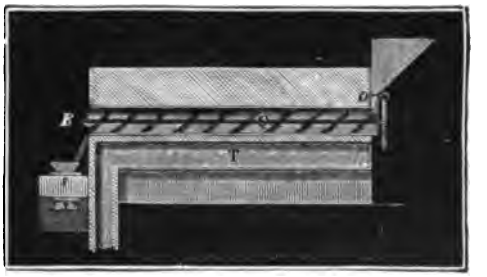


FIG. 121.

by means of the motion of the piston *y*. The moulds are filled from the vessel *S*, as the table is made to revolve by the movement of the lever *z*. As the moulds approach the cylinder *u*, the piston descends and compresses the fuel with an enormous pressure; after the piston rises, another set of moulds take their places, while the piston *y* of the cylinder *x* having descended at the other end of the table, the six bricks are forced out of the moulds, and are received below ready to be stamped with the maker's name. The machinery and the whole arrangements are exceedingly beautiful, and the accompanying sketch is only intended to convey an idea how the process is effected, without showing all the details of the mechanism.

The analysis of this fuel gave the following results:

Carbon	76.60	Coke { Carbon	61.67
Hydrogen	5.15	Coke { Ash	7.08
Nitrogen	1.54	Volatile matter	31.25
Oxygen	9.63		
Ash	7.08		100.00
	100.00		

The following table shows the composition of several specimens of artificial fuel, as ascertained by the officers of the Admiralty investigation.

Locality or Name of Coal.	Specific Gravity of Fuel.	Carbon.	Hydrogen.	Nitrogen.	Sulphur.	Oxygen.	Ash.	Percentage of Coke left by each Fuel.
Warlich's patent fuel	1.15	90.02	5.56	trace	1.62	included in ash	2.91	85.1
Livingstone's steam fuel	1.184	86.07	4.13	1.80	1.45	2.03	4.52	—
Lyon's patent fuel	1.13	86.36	4.56	1.06	1.29	2.07	4.66	—
Wylam's ,, ,,	1.10	79.91	5.69	1.68	1.25	6.63	4.84	65.8
Bell's ,, ,,	1.14	87.88	5.22	0.81	0.71	0.42	4 96	71.7
Holland and Green's	1.302	70.14	4.65	1.15	—	—	13.73	—

The pitch employed in the manufacture of the patent fuel had a sp. gr. of 1.01016, and yielded the following analytical results:

Carbon	73.56
Hydrogen	8.08
Oxygen	17.79
Ash	.57
	100.00

It contained no hygrometric moisture, and Wylam's patent fuel contained only 0.86 per cent.

A glance at the above composition of the pitch proves how valuable the substance must be in the manufacture of a fuel destined for raising steam on board steam-vessels. The large proportion of hydrogen and oxygen, add materially to the amount of flame it will produce, and the facility of its combustion. And it is obvious, that a fuel manufactured from this substance in proper proportion, with a suitable small coal, must far surpass any natural coal for steam purposes.

Some years ago the pitch produced from the distillation of gas-tar accumulated to such an extent, notwithstanding its application to patent fuel, as to be a very serious burden to many of the naphtha manufacturers, and in order to get rid of it they adopted a plan of converting it into coke and obtaining an additional quantity of pitch- or dead-oil. This process, now obsolete, was carried on in fire-brick ovens from 4 to 6 feet square by about 3 feet high, arched over at the top, from whence a large iron pipe carried off the very heavy vapours, which were easily condensed. The ovens had two doors opposite each other on either side; they were heated from

below, and when red hot a charge of pitch was introduced and distilled for several hours, the doors being closed. When the charge was worked off, the doors were opened, the pitch-coke removed, and air allowed to enter the kilns for some time, in order to burn off the thick coating of coke which had been deposited upon the sides and arch of the ovens from the decomposition of the tar vapours. The heat thus generated kept the walls at a red heat, and but little additional fuel was required to work off the following charge. The pitch-coke thus obtained was very dense and hard, and much prized by iron-founders and others on account of its small quantity of ash and its freedom from sulphur. Petroleum-still coke is the modern representative of this coke.

Warlich's Patent Fuel.—Warlich's object is to render patent fuel more capable of sustaining the heat to which it is subjected on board steam-boats, particularly in hot climates.

He employs the bricks made of the usual materials, but adds a little common salt or alum, to prevent the evolution of too much smoke, and subjects them in retorts to a temperature of 400° F. and upwards, for six to eight hours, while he assists the evolution of the gaseous matters by an exhausting apparatus. It should, however, be stated that the presence of sulphates, such as alum, tends to retard combustion, and is otherwise injurious because it involves the formation of sulphides, which attack ironwork.

Fig. 122 shows an elevation of a retort and furnace, and Fig. 123 a plan.

FIG. 122.

FIG. 123.

Fig. 124 is a transverse section of one of the retorts and furnaces.

Fig. 125 is the longitudinal section of the retort; *a* is the chamber in

FIG. 124.

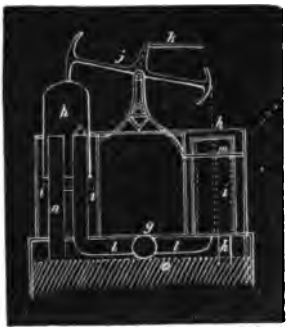
FIG. 125.

which the fuel is placed, and which is fitted with sliding doors; *c c* are the rails for the carriages, which have several shelves, on which the manufactured fuel is placed; *e*, eduction ways for the gases expelled from the

manufactured fuel, which by means of a dip-pipe *f* convey the products into the main *g*, as is practised in the manufacture of coal-gas.

Fig. 126 shows a section of the exhausting apparatus, which consists of two cylinders *h h*, open at bottom, working in vessels *i i* containing water. The motion communicated to the beam *j* by the connecting-rod *k*, alternately raises and lowers these cylinders; *g* is the main, with two branch-pipes *l l* and valves *m m* opening upwards; *n n* are two dip-pipes into the tank of water *o*. The products pass from the chamber retort into the main *g*, thence into the vessels *h*, whence they are forced below the water in the tank *o*.

Fig. 126.



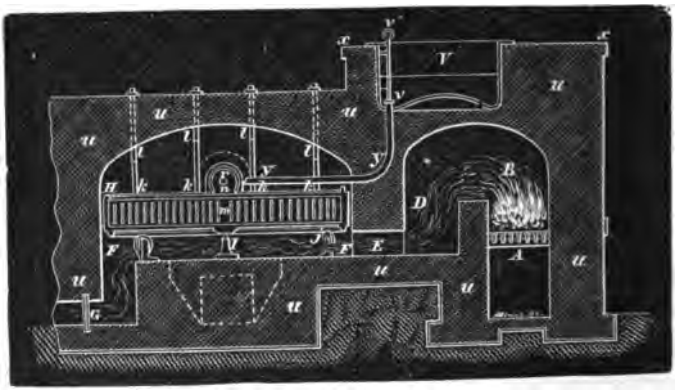
The fuel is heated in the chamber by a current of hot air, which passes into the retort through the openings *p p*.

The apparatus is similar to that suggested by J. D. Stagg and employed at Bagillt for condensing lead-fume.

Briquettes.—The following method is adopted at Blanzy for working up the small coal which accumulates in large quantities at the mines.

The coal, which is first washed in the ordinary way and dried, is mixed with 7 or 8 per cent. of tar in the cold, and made into bricks by means of the following machinery. In Figs. 127 and 129, *A* represents the ash-pit of a

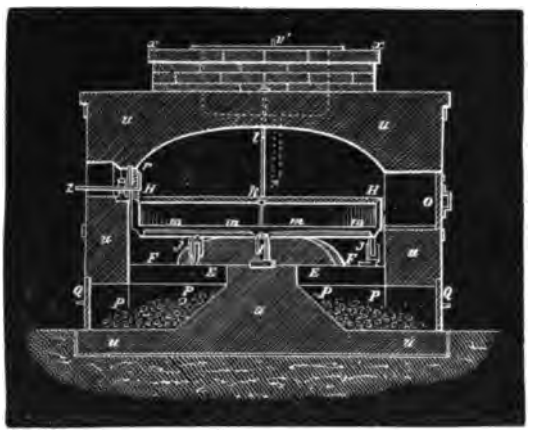
Fig. 127.



furnace, *B'* the metal plate between the door *C* and the grates *B*, *D* an arch to depress the flame so that it shall pass under *E* and spread itself over an extensive surface in *F*, where it heats a metal cistern turning on a pivot *I*. The smoke passes off by a chimney *G*; the metal cistern *m m* is driven by a pinion *r*, which works into the toothed edges *H H*. A rake *k k k* is suspended by the rods *k l*, which are built into the solid masonry *a a*. *V* is a boiler heated by the arch *D*, and a valve *v*, at the bottom, is opened or closed by the rod *v'*, to allow the tar to flow through the pipe *y y*. The coal prepared as already detailed, is thrown into the furnace by the opening *O*, Fig. 128, and the rakes spread it evenly over the surface of the metal cistern. The tar is admitted by opening the valve *v*, and as it flows through a pipe *n*, running the whole length of the rakes, it is more perfectly mixed with the coal, and a smaller quantity is sufficient to make a uniform mass. When the cistern is in the position indicated by the arrows, Fig. 129, the two scrapers *t t t t* are lowered together, and they carry the coal forward;

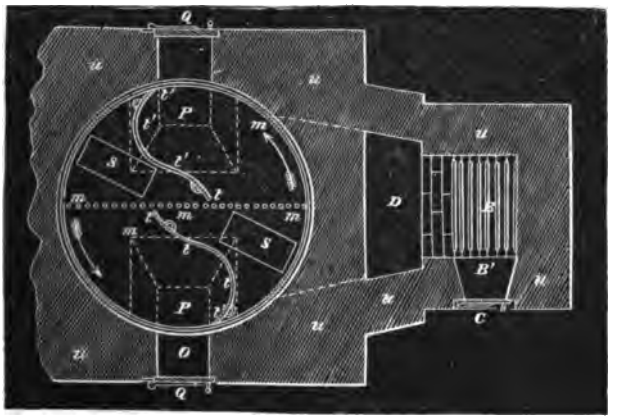
when the cistern has made $\frac{3}{8}$ of a revolution, the two trap-doors *s s* are opened, and the mass falls down into the receptacles *P P*. This warm mixture of coal and tar is removed through the doors *Q Q*, and pressed into bricks by a hydraulic machine.

FIG. 128.



Another modification consists in filling a series of moulds fixed on a moveable table, and by a mechanical contrivance forcing the bricks out of the mould at the same time.

FIG. 129.

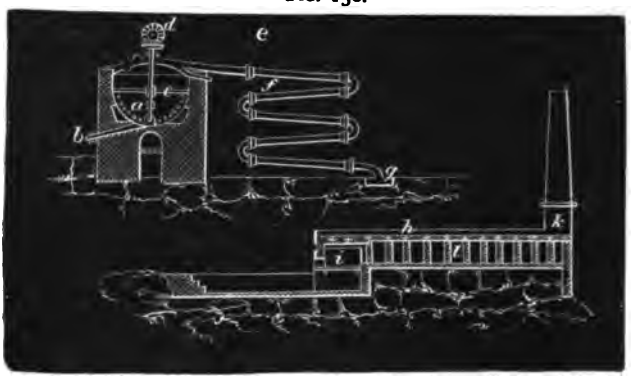


Mr. Wood proposed to make artificial fuel by mixing either coke or coal sufficiently small, in a heated state, with tar or pitch, in a common pug-mill, after which the mixture may be moulded in the ordinary manner.

Chagot's Artificial Fuel.—In the process for the manufacture of artificial fuel, by MM. Chagot and Co., of Chalon-sur-Saône, common coal-tar is mixed with small coal or carefully selected peat, in the proportion of 10 to 50 of the former to 100 of the latter. A certain quantity is then introduced into the still, shown in Fig. 130, where *a* represents the body of the still, with a discharge pipe and cock *b*, and an agitator inside *c*, driven by machinery at *d*. The cover is double, the inner being composed of sheet- and the outer of cast-iron, with a condensing worm *f*, supplied with cold water from a cistern at *e*, and discharging the products of distillation

at *g*. The usual products, naphtha, &c., distil over, leaving the pitch behind, which is run off, allowed to cool, and reduced to powder.

Fig. 130.



This pitch is ground and mixed with small coal, which has been previously dried on a flat surface at *h*, heated from below by the flues *l*. As soon as the material has been sufficiently incorporated, and the whole rendered somewhat soft by the heat, it is removed into moulds, and subjected to hydraulic pressure.

This is a very simple and obvious method of working up these waste products.

Bessemer's Patent Fuel.—The following patent process for consolidating refuse coal-dust is the invention of Sir H. Bessemer, from whose specification the following description is borrowed.

It is found that when coal or coal-dust is heated up to a temperature of 500° or 600° F., it becomes softened, the bituminous portions undergoing a degree of fusion sufficient to cause the small pieces to adhere together. It is this peculiar property of partial fusion in coal that Bessemer makes use of as a means of forming, by pressure, consolidated blocks or masses of coal, possessing the characteristic properties of the coal from which they are formed, but which have the additional advantage of being in pieces of uniform size.

Instead of forming the soft coal into large unwieldy masses, as usually practised in the manufacture of artificial fuel, and which require to be broken into pieces before use, producing much small coal or dust, it is made at once into small cylindrical bricks, of a size well adapted to furnaces or domestic use, while the trouble and loss of breaking is prevented, and a most convenient fuel obtained.

The machinery or apparatus employed for this purpose is represented by the drawings on Plate III. Sheet A, p. 224, where

Fig. 1 is a longitudinal elevation of a furnace, and an end elevation of pressing machinery.

Fig. 2 is a plan of the same.

Fig. 3 is a longitudinal section of the furnace on the line *a b* of Fig. 2.

Fig. 4 is a cross section of the furnace, and longitudinal section of the pressing machinery on the line *c d* of Fig. 2.

Fig. 5 is a side elevation of the pressing machinery, and an end elevation of the furnace; and

Figs. 6 and 7 are details of the travelling chain-bed, on a larger scale.

In this apparatus, the furnace for heating and softening the coal, the machinery for pressing it, and the steam-engine which produces the required motive power, are all combined, and constitute one apparatus; and as the

products of combustion will pass off from the furnace at a high temperature, it is intended that this surplus heat shall be applied to the generation of the steam required by the engine; for which purpose, a steam boiler, provided with suitable flues, should be set as near as convenient to the end a^* of the furnace a, where it will be perceived that an opening is left at b, Figs. 1 and 3, for the purpose of allowing the heated matters from the furnace a to pass into the flues of the steam-boiler, the arrangement of which is so well understood as not to require detailed description.

The furnace a is of the reverberatory kind, and has a fire-place at c, provided with fire-bars d, and doors; $e f$ is an endless chain-bed, of peculiar construction, passing over polygonal drums g, mounted on axes h; the horizontal position of the chain f is ensured by small iron rollers i, which support it at short intervals; the rollers i are provided with axes, which work in iron sockets let into the side-walls of the furnace; as also the axes h^* of the polygonal drum g^*. The chain-bed consists of a number of iron bars of about 30 inches in length, notched on each side, and fitting into each other in a similar manner to a common hinge-joint, and like the hinge, it has a pin passing entirely through it, and thus forms a joint capable of folding over the polygonal drums g, and also of presenting a nearly flat surface on the upper side (see Figs. 6 and 7, where a part of the chain-bed is shown on a larger scale). Near the end of the furnace farthest from the fire, a hopper j is fixed, into which the small coal is thrown; this hopper has a roller k, with leaves projecting from it, working in a cylindrical part formed in the hopper. The roller k is mounted on a shaft l, which turns in bearings formed in the bosses cast on the sides of the hopper j. The shaft l is also supported by a plummer-block n, and carries on its outer end a drum m, which receives motion from the strap o, and causes a regulated quantity of the small coal to pass from the hopper, through the opening p, and fall upon the endless chain-bed in a thin layer; the motion of the chain-bed in the direction of the fire-place c will bring the coal along with it, and discharge it into the hopper r. To prevent any portion of the coal that may stick to the chain from being carried back again, a scraper s is made to press its edge against the lower part of the chain; the scraper is mounted on an axis, and has a lever and ball q, the weight of which presses the edge of the scraper against the chain. It will be seen that the fire-bridge t rises sufficiently high to protect the chain from the violent action of the fire, and it at the same time forms one side of the hopper or receptacle r.

A break is shown in the drawing, to denote that the furnace and chain-bed are to be made longer than is there represented: from 30 to 40 feet of bed will be found to answer well.

When a fire is made in the fire-place c, the heat will be reverberated on to the thin stratum of coal upon the chain-bed, which as it first enters from the hopper is subjected to the lowest temperature of the furnace, and brought progressively into the hotter part, near the fire-bridge; while new portions of coal are deposited upon the chain-bed, as it passes under the hopper j, which are in turn carried towards the fire-bridge. The increased temperature to which it is thus subjected will cause the coal to soften, and commence to give off some of its volatile constituents, which, when inflamed, add to the action of the furnace.

The extent to which the fusion of the coal is carried may be regulated by the speed at which the chain moves, and also by the state of the fire: the small coal being thus softened by heat, and delivered in a regular and continuous stream into the hopper r, is then to be pressed by an apparatus constructed in the following manner:—A, is a strong bed-plate or frame, forming a sort of rectangular box having a flange A^1, extending around the upper side, and another flange at the lower side connected to the upper one

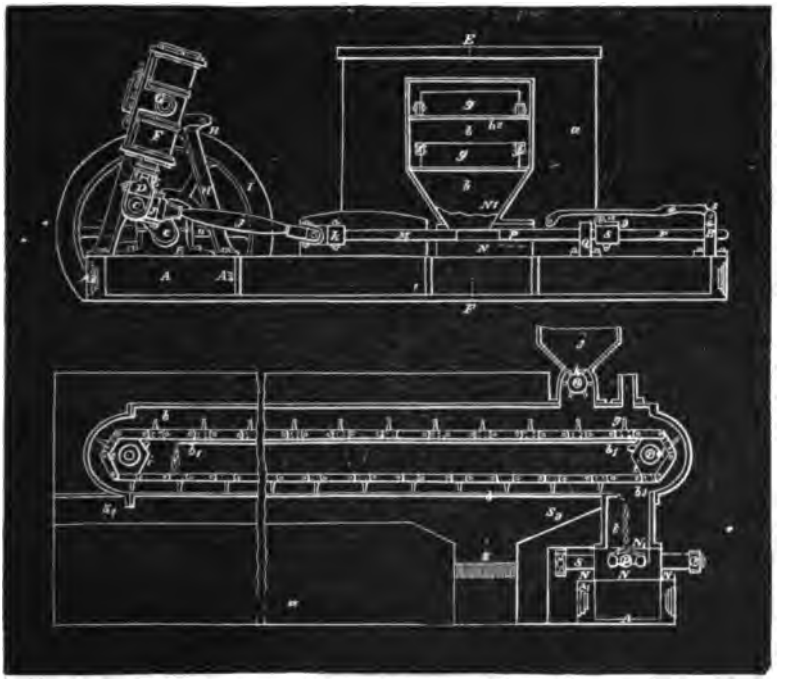
by ribs A², and dividing it into panels; externally, upon the upper flange of the bed-plate, are bolted the plummer blocks B, which support the trunnions of an oscillating steam cylinder C, which, with its steam-pipes, slide-valve, and valve-gear, may be constructed in the ordinary way; D is a one-throw crank of great strength, working in plummer blocks E, and carrying on one end the fly-wheel F. The piston-rod G of the steam-cylinder is connected to the crank by a jib-head G*; there is also connected to the same crank-throw a connecting-rod H, having a double jib-head, so as to take hold of the crank on each side of the piston-rod G; the other end of the connecting-rod H is jointed at H* to the cross-head I, which moves in slots formed in the guides J J, which are bolted to the upper flange of the bed-plate A. One end of the bed-plate A passes through the lower part of the furnace *a*, and has bolted to it at that part a massive piece of iron K, with two cylindrical holes bored entirely through it parallel to each other, and which for distinction are termed the pressing-cylinders; the piece K is held firmly in its place by bolts, and is moreover prevented from moving by projecting pieces K*, which abut against the flanges of the frame A; the upper side of the piece K has an opening or hopper *r** through which the softened coal falls into it. There are two plungers L L fitted to the cylinders, and keyed into the cross-head I, so that the revolution of the crank by means of the connecting-rod H, and guides J J, will produce a reciprocating motion of the plungers L L. The crank D has keyed upon it at one end a bevelled pinion M, working into a bevelled wheel N, which is mounted on a shaft P, supported by plummer blocks Q Q; and at the other end of the shaft P there is a spur-wheel R in gear with another wheel S on the axis *h* of the polygonal drum *g*. This axis *h* also carries a drum T, over which the strap *o* passes and communicates motion to the roller *k*, and thereby regulates the supply of coal upon the chain-bed. The action of the apparatus will be as follows.

Steam having been got up in the boiler by a fire made temporarily under it for that purpose, and the fire lighted in the fire-place *c*, the working of the apparatus will commence whenever a communication between the boiler and steam-cylinder is opened, the rotation of the crank-shaft will put in motion the bevel-wheels M and N, and the shaft P; and by means of the spur-wheels R and S, the shaft *h* of the polygonal drum *g* will receive a rotatory motion much slower than the crank-shaft, by reason of the difference in the diameter of the wheels made use of for that purpose, and thus a slow travelling motion will be given to the chain-bed. The shaft *h* also carries a drum T, which, by means of a strap, gives motion to the drum *m* and feeding-roller *k*, and thereby causes a regular supply of small coal to fall upon the chain-bed, as it passes under the hopper; the reverberated heat from the crown of the furnace acting on the thin stratum of coal upon the bed will cause a partial fusion or softening of its bituminous parts before arriving at the hopper *r*, into which it falls. While this action is regularly and continuously going on, the crank-shaft of the apparatus will, by means of the connecting-rod H and cross-head I, give a reciprocating motion to the plungers L L, which work in the cylinders K, and pass along the lower part of the hopper *r**, and push before them the softened portions of coal into that part of the cylinders marked K¹; the extreme distance to which the ends of the plungers move is indicated by the letter Z. When the crank commences its backward movement, the plungers will also recede until they assume the position represented in the drawing. While this retrograde movement of the plungers is taking place, some portions more of softened coal will have fallen down from the endless chain-bed, and have been deposited in the hopper and upon the plungers; but as the plungers recede, as before stated, into the position shown in the drawing, the coal which has fallen upon them will fall off again into the space occupied by them; and when the plungers again advance, a

fresh portion will be forced into the cylinders K¹, but as the plungers move forward an equal distance each time, the portion of coal pushed forward will be forced against the portion of coal left there by the former stroke of the plungers, and not only will it be forced against it, but it will move it farther along the cylinders K¹ until the last portion occupies the place of the former one; and thus, by the continued action of the plungers, fresh portions of coal will be forced into the cylinders K¹. It will be observed that the cylinders K¹ are open at the end, and it is towards this open end of them that each successive portion of coal is forced by the plungers; the friction of the mass of coal in sliding along the cylinder is very great, and the resistance thus opposed to the motion of the plungers L L causes a powerful compression of the fuel to take place, which is finally projected from the end of the cylinders in a solid and compact state, as shown at W.

It has been already stated that the surplus heat of the reverberatory

FIG. 131.



furnace may be applied to the production of steam for supplying motive power for the working of the apparatus, and in some cases it may be deemed advisable to heat the coal by this process sufficiently to ignite it, and cause a combustion of the more volatile portions, by which more heat will be communicated to the boiler, and a fuel produced having many of the peculiar and valuable properties of coal, but at the same time not possessing sufficient bituminous matter to cake together when used in a furnace or common fireplace; from the same cause it will not produce a dense black smoke, and will be capable of being used in many cases where coke is now employed.

The apparatus described above is preferred when a fuel differing very little from ordinary coal is required, and the heat is only sufficient to cause the necessary adhesion amongst the small pieces and dust. If more gaseous matter is to be removed, or different kinds of coal refuse are to be mingled

and heated so as to produce a fuel differing from coal and more analogous to coke, the following arrangement of apparatus is employed.

In order that the volatile products given off by the coal while it is undergoing the softening process may be utilized, as well as those portions which are purposely expelled in order to modify the quality of the fuel, and enable it to be made in lumps of definite lengths, an apparatus is constructed in which the retort furnace for heating the small coal, the pressing machine for solidifying the fuel, and the engine for producing the motive power, are combined so as to constitute one apparatus, as represented in the drawings on Sheet B, Plate III., page 224, and Figs. 131 and 132, where—

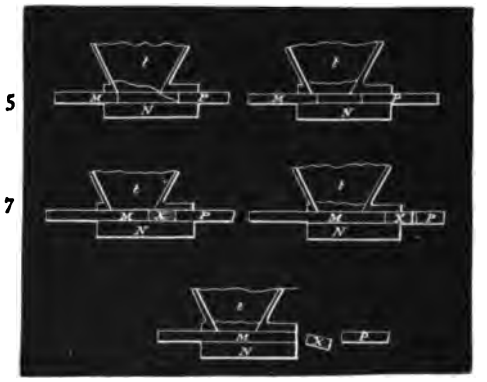
Fig. 1, Plate III., page 224, Sheet B, is a longitudinal elevation with the steam-cylinder omitted.

Fig. 2, a plan of the same.

Fig. 131 shows, firstly, a longitudinal section on the line A B of Fig. 2, with the position of the steam-cylinder; and secondly, a longitudinal section on the lines C D of Fig. 2, Plate III., page 224, and E F of the sketch on p. 219.

Fig. 132 shows various sections of the pressing apparatus at different stages of the pressing process.

Fig. 132.



In the furnace *a* is fixed the rectangular vessel or retort *b*, which is shown broken through, to indicate that its length should be greater than represented in the drawings; about 30 feet in length will be found to answer well; it should (for convenience of putting up) be made in three lengths united by flanges, and the joints made tight with iron cement; one end of this retort projects from the furnace, and overhangs a part of the pressing apparatus. The retort has a partition b^1 extending nearly the whole length of it, and in a tangent line with the upper surface of the polygonal drums *c* and *d*, over which two endless chains *e* and *f* are made to pass (see Fig. 2 on Plate III., p. 224, and Fig. 131); the chains *e* and *f* are connected together by broad plates of iron *g*, with flanged ends, which are riveted at *h* to the single links of the chains; the edge of the plates *g*, which project beyond the chains, is bevelled so as to form a scraper; the polygonal drums *c* and *d* have projections *i* formed upon them, which fall into the spaces between the double links of the chains, and ensure the motion of them when the drums *c* and *d* are turned round. On the upper side of the retort there is fixed a hopper *j*; the lower part of the hopper, in which the coal-dust or small coal from which the fuel to be formed is placed, is made to fit closely to the leaves or ribs projecting from the feeding drum *k*; there are bosses *l* formed on the sides of the hopper, in which the shaft *n* of the feeding-drum revolves; there are also bosses (not seen in the drawings) formed on each side of the retort

for the axis of the polygonal drum *c* to revolve in; and on the outer projecting part of the retort are formed two other bosses *o* and *p* for the axis *r* of the polygonal drum *d* to revolve in. One end of this axis is elongated, and passes through a stuffing-box formed on the boss *p*, so that none of the volatile matters within the retort can make their escape at the part through which motion is transmitted to the interior.

The action of this part of the apparatus is as follows:—A fire having been lighted in the fire-place *s*, the heat passing under the retort escapes with the products of combustion at the open end of the flue s^1, where it may be made to circulate about a steam-boiler, for the purpose of generating the motive power required to work the apparatus. It will be preferable to set the retort so that the heat may ascend a narrow space between the sides of it and the brickwork of the furnace. An enlargement of the fire-chamber is shown at s^2, for the purpose of transmitting radiant heat to the under-side of the projecting part of the retort. The temperature of the furnace having brought the retort up to a heat approaching redness, the feeding-drum is put in motion, when the small coal or coal-dust will be deposited upon the shelf b^1; but the motion of the chains and scrapers in the direction indicated by arrows, will move it along the shelf; and as each scraper comes in turn under the feeding-drum, the coal which has fallen between each of them will be carried forward to the end of the shelf b^{1*}, off which it falls on to the lower and hotter part of the retort, and, as before, occupies the space between the scrapers. It will be observed that the entire weight of the chains and scrapers rests on the bottom of the retort, so that by their constant passage over it, the coal is prevented from sticking to it, and rendering its interior surface uneven. The action of the scraper not only impels the coal forward, but turns it over as it passes along, so as to present fresh portions of it to the heated surface of the retort, and thus ensure an equal effect on the whole of the coal-dust, which, becoming softened, is moved in that state over the opening b^2, in the lower side of the retort, and falls into the receptacle *t*, where it is submitted to the following operations.

A is the foundation-plate or framing of the pressing apparatus: it is a sort of shallow box, having a flange A^1 around its upper edge, connected to the lower flange by vertical ribs A^2, which divide it externally into panels, the interior portion of the framing being also divided by ribs A^3, by which its strength is increased. Upon the flange A^1 are bolted the plummer-blocks B, which support the crank-shaft C, made very strong to withstand the strains to which it is subjected. The crank has only one throw formed on it, in the centre of which is attached, by a gib-head D, the piston-rod E of the oscillating steam-cylinder F. The steam-cylinder, with its induction and eduction-pipes, slide-valve, and other necessary appendages, may be constructed in the usual way. These parts have been omitted in all the figures, except in Fig. 131, where the steam-cylinder is represented in the position it would occupy at the particular part of the crank's motion there represented. It will be observed, that the steam cylinder is placed, with its axis, in a line vertically over the crank-shaft, and is there supported by trunnions G, working as usual, in plummer-blocks bolted to the two frames H H; these frames have lugs cast on them at H*, through which stretchers are to pass in order to steady them; the frames H are bolted at foot to the flange A^1 of the bed-plate.

In order to regulate the motion of the apparatus, the fly-wheels I I are keyed one on to each end of the crank C. A stout connecting-rod J is made with a double gib-head J*, to embrace the gib-head D, and thus to receive motion from the same crank-throw. The other end of the connecting-rod J is jointed by a gib-head and pin to two lugs K*, which project from the stout cross-head K; the ends of this cross-head slide in guides L L, which are

secured by bolts to the flange A¹ of the bed-plate. There are three plungers M M M keyed into the cross-head K, and work in cylindrical holes, bored truly through the massive block of iron N; this block N is bolted to the bed-plate by a flange N*, and is keyed up between steps Z, cast on the bed-plate. The upper part of the cylinder block N has a large opening N¹ made in it, through the bottom of which the plungers M move; and immediately over the opening N¹ is the receptacle into which the softened coal falls from the retort. The cylindrical holes in the block N have another set of plungers P P P, working in the opposite end of the holes to that occupied by the plungers M M M. On the flange A¹ of the bed-plate are bolted two guide-bars Q and R, having holes bored in them of a size to fit the plungers P P P, which are made long enough to work through both these guides; so that when the plungers P P P are entirely withdrawn from their respective cylinders in the block N, they will be so guided as to re-enter them without difficulty. The plungers P P P are keyed to a cross-head S; on the ends of the cross-head S there are fitted with gib-heads two long connecting-rods T (see Fig. 2, Plate I., as they are omitted in the rest of the figures). The opposite ends of the connecting-rods T are provided also with gib-heads, and work on crank-pins U, which project from one of the arms of each fly-wheel I I. These crank-pins U U are so placed with reference to the central crank-throw C that the latter forms an angle of 45° to the crank-pins; that is, the one is one-eighth part of a circle in advance of the other, and thus the action on their respective plungers will be such that they will alternately approach and recede from each other at each end of their respective strokes.

It has already been described how the small coal is made to traverse the retort and be deposited in the receptacle. The means whereby the requisite motion is given to the chain and feeding-drums is as follows:—Over one of the fly-wheels I a strap is passed, which works upon a drum V on the shaft W; on this shaft W there is a worm X which works on the upper side of the worm-wheel Y, which is keyed on to the shaft *r* of the polygonal drum *d*; the shaft W also carries another worm 1, which works into the lower side of the worm-wheel 2, keyed on the axis *n* of the feeding-drum. The shaft W is supported in bracketed plummer-blocks 3 3, which project from and are bolted to the side of the retort, so that whenever the fly-wheel is put in motion, the intermediate wheels and shaft last described will transmit the requisite motion to the scrapers and feeding-drum. From previous descriptions, it will have been understood how the steam-piston, acting on its crank, will put in motion the whole apparatus, which will be regulated by the fly-wheels, and in what manner the cross-heads K and S will be acted on by their respective connecting-rods, and how the set of plungers M M M, and plungers P P P, are made to reciprocate in their respective ends of the block N; but in order to show more clearly the way in which they are made to approach and recede from each other five sectional drawings are shown on Fig. 132, by which the relative positions of the two sets of plungers, with reference to each other at different parts of their stroke, will be seen; and to render this explanation more clear, we may suppose the operation to commence when the crank-throw C and its connecting-rod are in a horizontal position, and the plungers M M M withdrawn as far as possible from the block N. This position is represented at 5, Fig. 132, where it will be seen that the fuel in an uncompressed state has fallen down and occupies the space in the front of the plungers M. If we now make one-eighth part of a revolution the plungers M will be moved forward a little, as shown at 6 and in Fig. 131, where it will be seen that the crank-pins U U have risen up to the horizontal line and brought the plungers P nearer towards the centre of the block N; if we now give another eighth of a turn to the crank, the plungers N will have advanced a considerable distance, being at half-stroke, and at the same time the plungers

P will have receded into their starting position, as represented at 7. Here it must be observed that the soft coal, which was carried forward by the plungers M, is compressed between the opposing ends of the two sets of plungers. In this position of the plungers there is a small space at z (*vide* 7), where any surplus quantity of coal may squeeze out before it is made to enter the close part of the cylinder, after which they will approach a very little nearer to each other and thus give the final pressure. If another eighth of a revolution is now made, the relative positions of the crank and crank-pins will give a quicker motion to the plungers P, which will commence receding from the other plungers M, and thus leave no pressure on the solidified lump of coal X; were not the pressure thus relieved, the lump of coal as it merges from its cylindrical hole in the block N would be broken, there being no longer any circumferential support for it. This position of the apparatus is shown at 8. Another eighth of a turn will complete a single stroke of the plungers M, and have entirely expelled the block of coal X, which is represented as falling down at 9; the plungers P have receded still farther, and allow ample space for the block of fuel to fall. Another eighth of a turn will commence the return stroke of the plungers, and by following on in the same way until one complete revolution is performed, the respective plungers will again have resumed the position represented at 5, and be ready to renew the operation.

If three plungers are made use of, as here represented, three blocks or cylinders of fuel, of equal length and diameter, will be formed at each complete stroke of the engine. As there is a tendency in the block of fuel to stick to the plungers M, a detaching frame is placed at the end of the machine where the blocks are expelled. 4 4 are thin bars of iron fixed on an axis 5, the ends of which work in lugs 6 on the guide-bar R; the other end of the bars 4 4 are connected together by a rod 8, and upon the cross-head S there are bolted two small frames 9 9 which carry rollers 10; upon these rollers the bars 4 4 rest, and when in the position shown in Fig. 131, the bars are supported a little distance above the plungers P; but when the cross-head S moves backward, and allows the blocks of coal to be projected outward by the plungers M, then the roller will pass under the inclined part of the bars 4*, when they will descend by their own weight, and the rod 8 will come in contact with the blocks of coal and detach them from the ends of the plungers; if they should adhere, the reverse motion of the cross-head S will again raise up the bars 4 in readiness for a repetition of the process.

From what has been before stated in reference to the softening process by heat, it will have been understood that the coal-dust may be made to traverse the shelf b^1, where it will receive a preparatory heating, and afterwards traverse the bottom of the retort so quickly as to produce such a light effect on the bituminous portion of the coal as only to soften it a little and render it fit for the operation of compressing into solid lumps possessing the general properties of the coal from which it was produced. But one of the great objects of this apparatus is to alter and modify the composition of the resulting fuel by driving off certain of the volatile constituents of coal, and thereby rendering such fuel more fitted for certain processes in the arts than ordinary coal. To effect this object, the speed of the feeding and polygonal drums may be regulated so as to subject the coal to any assigned period of operation, and the intensity of the fire being also regulated, the extent to which the distillatory process is carried will be under perfect control; the gaseous matter given off from the coal as it passes into the hottest part of the retort over the fire-plate *s*, will have to pass over the surface of the coal which is advancing in that direction, and help to heat it, while it also assists in transmitting heat to the under side of the shelf b^1. It will ascend through the opening b^{1*}, and pass along over

the coal-dust spread upon the shelf, and farther assist in heating it, and finally make its escape through the pipe *u*. This pipe should have an elbow descending in the manner usually adopted in gas-works, and known as the hydraulic main. In this vessel, the liquefiable portion of the volatile matters will be condensed, and the gas may be passed into a gasometer, where it may be stored and used. The fuel resulting from this partial distillatory process will be found to be less fusible in the furnace than ordinary raw coal, and consequently the caking in the furnace will be prevented.

In order to facilitate the evolution of gaseous matters from the coal at as low a temperature as possible, and to increase the density of the compressed fuel, an air-pump, constructed in the manner generally employed for exhausting sugar vacuum-pans, is used. The pump is connected with the pipe *u*, Sheet B, Plate III. (opposite), and by the application of steam or other motive power the retort is kept in a state of exhaustion, which should, if possible, be equal to 24 or 25 inches of mercury in the barometer; the effect of this exhaustion is to cause the liberation of the gas from the cells and interstices of the fuel, and to render it more dense and compact when pressed. When the air-pump is used, the eduction valves must be made to communicate with the hydraulic main, so that the gaseous matters pumped out may pass off into the gasometer.

Instead of applying fire directly to the under side of the retort, as shown in Sheet B, highly heated steam may be used for the purpose of heating and softening coal, to be afterwards pressed into lumps or cylindrical pieces. For this purpose, a set of cast-iron pipes is arranged in a furnace in the same way as is now commonly used for heating air for hot-blast furnaces, and also for heating steam. Into one end of this series of heating pipes, the waste steam of the engine is allowed to pass, and the pipes being kept at a red heat, the steam will acquire a very high temperature, and in that state is to be supplied to the interior of the retort for the purpose of softening the coal; in this case, the retort, which may be made in the same manner as that represented in Sheet B, but will not require any fire-place or flue beneath it, but should be enclosed in brickwork or other bad conductor of heat; the pipe which conveys the steam should enter at the hopper *t*, the steam escaping with the gases through the pipe *u* into the hydraulic main, where condensation will take place, the gases passing off to the gasometer.

In addition to the processes described above, the following plans have also been suggested or patented for preparing artificial fuel:—

Bell proposed to use pitch, asphalte or bituminous matters, and small coals in a pug-mill, whose knives and shafts are hollow, so as to be heated with steam, and then moulded.

Cobbold agitated peat in water by means of machinery, so as to separate the earthy matter, and allow the peat afterwards to subside.

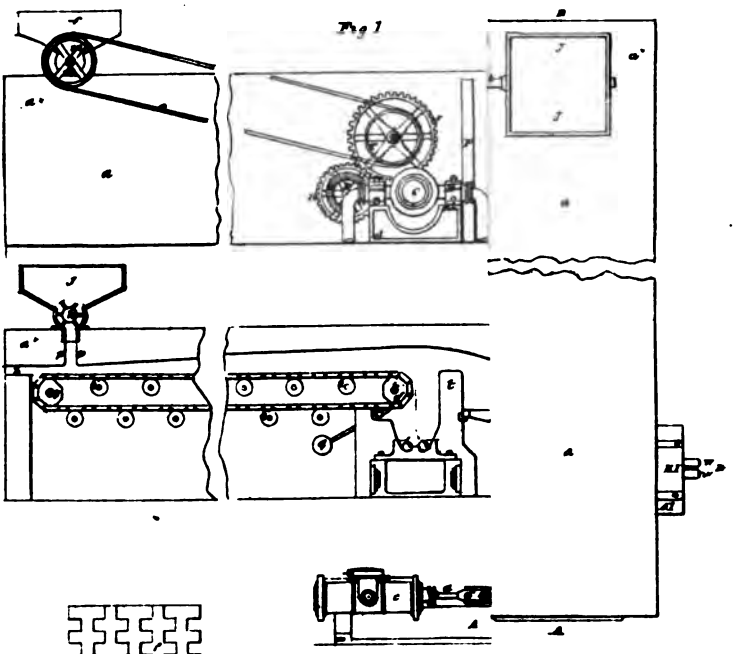
Dobree proposed to heat ground small coals, breeze or cinders, and pitch, &c., in close vessels with high-pressure steam, which will so amalgamate the whole that they may be moulded.

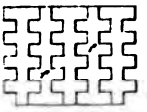
Godwin proposed to make bricks from mud, or clay, ground up with pitch and coals; and

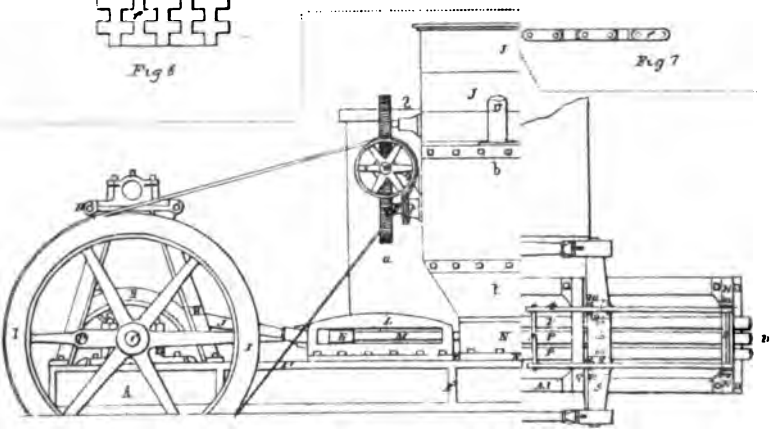
Greary to melt pitch, coals, tar, sawdust and clay together for the same purposes.

Holcombe proposed to run a mixture of tar, pitch, dead-oil, &c., over bricks formed of limestone or other porous materials.

Mohun mixed alum, nitre, peat coke, &c., in a pug-mill, and afterwards compressed them into moulds. This combination in one substance of an anti-combustible like alum, and a powerful oxidizing agent like nitre, is remarkable.







To face page 22

Oram used tar, coals, mud, &c., and compressed them into moulds, after being previously carefully mixed and sifted.

Stirling used the ordinary materials but exposed the bricks to a temperature of 250° F. afterwards.

Warlich heats his bricks in large kilns up to a temperature of 400° or 600° F., to expel all the gaseous constituents, exposing the square bricks, so as to make coke in the usual way.

Hill's process consists in distilling peat in the same way as wood, and mixing the residual charcoal with the hot pitch, so as to form lumps or bricks on cooling.

Lowe saturated dry blocks of peat with tar or other carbonaceous fluids in large cisterns, by means of heat.

Holland mixed gypsum, lime or cement with tar or small coals, and compressed the mixture into moulds.

Buckwell simply employs enormous pressure to form bricks out of small coal, or breeze from coke, whilst

Rees submits such materials in moulds to a temperature of 500° to 990° F., which, partly melting, adhere on cooling and form solid masses suitable for use.

Brooman substituted gutta-percha as the binding ingredient when using the usual materials, whilst

Ransome employed a solution of silicate of soda for the same purpose.

W. H. Cory, of Cardiff, invented a method of utilizing slack or small coal, which is said to have been in successful operation since 1873. The process (which Percy, however, states was first patented by Mr. John Bethell in 1854), consists in mixing the slack or dust with fireclay and silicate of soda (for bituminous coal, 2 per cent. of clay and 3 per cent. of silicate), and subjecting the block to a pressure of a ton to the square inch of the block surface. The block thus formed is as hard as ordinary coal, and has all its angles rounded to prevent chipping. The surface is glazed by the manner in which the pressure is delivered, and the press turns out 240 tons in twenty-four hours. The blocks require twenty-four hours to become hard and fit for use. During that time, the required chemical action takes place, the clay converting the silicate of soda into alumino-sodic silicate, which vitrifies the block and causes it to be weather proof.

A very simple plan was introduced in 1867 or earlier in Austria by Von Stummer-Traunfels, who was engineer to one of the State railways, the locomotives of which used his briquettes. He mixed a certain proportion of farinaceous, amylaceous, or glutinous matter with a certain proportion of fibrous material, and these being boiled together to form a cement were then mixed with coal-dust or small coal, and moulded into bricks. He stated that he found the cost of working the process to amount to two shillings per ton, including cement.

Stummer was evidently not the first to use farinaceous material for agglomerating small coal, as Percy refers (p. 465, "Fuel") to Barker's patents of 1864 and 1865 for the manufacture of artificial fuel by means of mucilage made from any farinaceous substance. But Barker stipulates that the gluten should be first removed, whereas Stummer employs it for its binding qualities.

Percy also records that, according to Mr. Prim, a native of Killarney, it was the practice in Ireland previously to the potato famine to boil potatoes unpeeled, and that the stiff pulp obtained by pounding their skins with the addition of a little water, was mixed with coal-dust and sufficient water to make a mixture about the consistency of stiff mortar. The mass was then well mixed, moulded by hand into oval-shaped balls, which were stacked in a dry cellar for use as fuel for domestic operations.

The processes of Barber and Bethell have been introduced practically in Britain, but the artificial fuel or fuel brick industry has never made any great advance in this country, no doubt on account of the abundant supply of cheap coal. It may come to the front, however, at any time in consequence of the efforts made by coal producers to economize in various directions and to improve, by washing, screening, &c., the quality of the slack which they sell.

On the Continent, however, it is a well-established industry. Under the name of Peras, artificial fuel made from small coal of screenings, dust, &c, washed, ground, and mixed with thick coal-tar and moulded into bricks under pressure, has been known in France for a considerable time. So also has the moulded charcoal or Parisian coal introduced many years ago by Popelin-Ducarré, and the use of coal briquettes on Austrian railways has already been referred to. The briquettes possess several advantages—they are less friable than coal lumps when properly made, and being of regular shape are more easily stowed. For domestic use they have the advantage of not soiling the hands, and they can be purchased by number, so that a check is kept on the weight supplied.

Within the last few years, the manufacture of coal briquettes has attained considerable proportions in South Wales, and during 1886 the development of the manufacture commenced in Scotland. This is the outcome of the recovery of large quantities of tar from blast-furnace gases, the tar being of low quality and practically unsaleable for the extraction of benzene or the more valuable hydrocarbons from it. Messrs. Wm. Baird & Co. have started this, for Scotland, new industry at their Lugar Ironworks, South Ayrshire, where the coal-dust or dross used is that of very fine coal known as the Bute Jewel Coal, a good household coal. The dross of this coal is first carefully washed, and is then sorted by passing through screens of five different meshes. Of the classes of sorted fuel, the larger (nuts and peas) are used without further manufacture, but the finer classes are dried and ground, and then mixed with a proportion of pitch powder, when they are compressed into small blocks by hydraulic rams—the pressure exceeding 2 tons per square inch. The result is a brick-shaped block of coal, clean and compact, but yet easily combustible and containing under 3.6 per cent. of ash. The plant at Lugar Works is capable of turning out 200 tons of briquettes per day.

GASEOUS COMBUSTIBLES.

Although the practical use of gaseous fuel has been accomplished on anything like a general scale only in recent times, yet the knowledge of its value and of several sources of supply dates back nearly ninety years.

In 1801, Lampadius proved the possibility of utilizing the waste gases escaping in the carbonization of wood, and in 1809 to 1811 M. Aubertot employed the waste gases of blast furnaces for roasting ores, burning lime, &c. In the year 1811 or 1812, a patent was granted to Aubertot for the application of these gases to metallurgical purposes, and in 1814 he is found advocating the building of suitable furnaces for their employment.

A Report communicated to the French Academy of Sciences in May 1842, by MM. Thenard, Berthier, and Chevreul, mentions these facts.

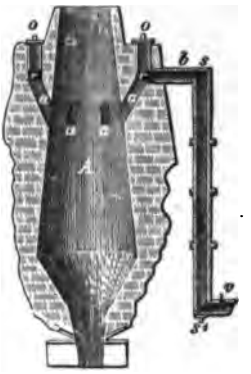
Lampadius in 1830, at the Lead Smelting Works of Halsbrücke near Freiberg, attempted to employ the flame of coal-gas in cupelling silver lead; and in 1837, the use of waste gases was carefully investigated by Faber du Faur, who carried out some laborious experiments at an ironwork in Würtemburg. These experiments attracted attention widely to the advantages of employing the waste gases from blast furnaces as fuel, and may be said to have led to the present almost general adoption of that method of working.

The property of burning with flame is common to most of the natural fuels, and is due to the evolution and combustion, at a high temperature, of the combustible gases, carbonic oxide, hydrogen, hydrocarbons, &c.; but even those fuels which, like charcoal and coke, usually burn with little or no flame, may be made to afford combustible gas under peculiar circumstances—for instance, when ignited in large quantities, with a limited supply of air—when a large proportion of the carbonic acid at first produced becomes converted by contact with red-hot charcoal into carbonic oxide. Any solid combustible may thus yield gaseous fuel. As the process of dry distillation, in which the whole of the combustible gases may be obtained from fuel, involves too serious a cost in the extra firing to be applicable to the production of gaseous fuel, a plan of burning the solid fuel in large quantities, with the admission of a limited supply of air, is resorted to, and a special apparatus or producer is employed for this purpose. In many cases, where gaseous fuel has been much employed, it is obtained as a waste product from blast furnaces, which has only to be collected in proper flues, and conveyed by pipes to the place of consumption. In the latter case, the mode of production is similar, and the chemical constitution of the gases from the two sources is practically the same.

Waste Gases from Blast Furnaces.—The method of conducting away the waste gases from an iron-furnace, as carried out by Faber du Faur, is shown in Fig. 133.

At the proper distance from the throat of the furnace *A* (from 3 to 12 feet, according to its construction), several apertures *a a a* are made in the sides, from which flues lead to the annular flue *r r*, the latter being connected with the iron pipe *b* for conveying the gases to the place of consumption. The flow of gas can be regulated by the damper *v*, and above each aperture *a* is a moveable lid *o* for the purpose of cleaning the flues from furnace-dust. Closed apertures at *s* and *s*¹ admit of the pipe being cleaned.

FIG. 133.



Mr. Budd, of the Ystalyfera Iron-works Swansea, applied the heated gases which escape from the anthracite furnaces for heating the blast and raising steam in the blowing-engine. In his arrangement, the excess of heat of the gases only was employed, as they were not ignited, but simply passed over the pipes which convey the blast, and through the pipes which pass through and over the boilers. A similar arrangement to that shown in Fig. 133 was adopted, the apertures being, however, only about 3 feet from the mouth of the furnace; the hot-air pipes were enclosed in an oven on a level with the outlet pipe *b*, and the gases drawn away by a small chimney in connection with the ovens. This is practically the plan which was tried at the Dundyvan Iron-works in Scotland (now extinct) about the year 1850, although Fig. 134 shows that the passages for escape of the gases were made very narrow in that case.

Experience led to improvements in this plan, and a modern modification of it was adopted by the Messrs. Addenbrooke* in Staffordshire, and at Summerlee Iron-works in Lanarkshire.

At Coltness Iron-works, in Scotland, a similar arrangement of furnace was in operation in 1852, but with decided improvement in the design of apertures for the escape of the gases over that shown in Figs. 133, 134.

* See "Proc. Inst. Mech. Eng.," 1865, pp. 235–255, plates lxvi.–lxx.

The channels, pipes, or mains for conducting the waste gases were, however, at that early day, made very much too small, and becoming choked, or partially choked, with tar and soot, prevented the proper action of the system, and led to disappointment and loss on the part of those who were the pioneers (in this country) in introducing this improvement. In the Cleveland district where the system of utilizing the waste furnace gases was re-introduced in its modern shape, the furnaces are worked entirely with coke, and hence there are no tarry hydrocarbons in the waste gases.

Fig. 134.

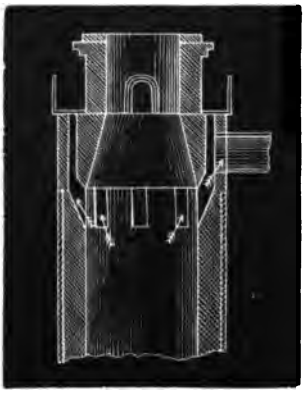
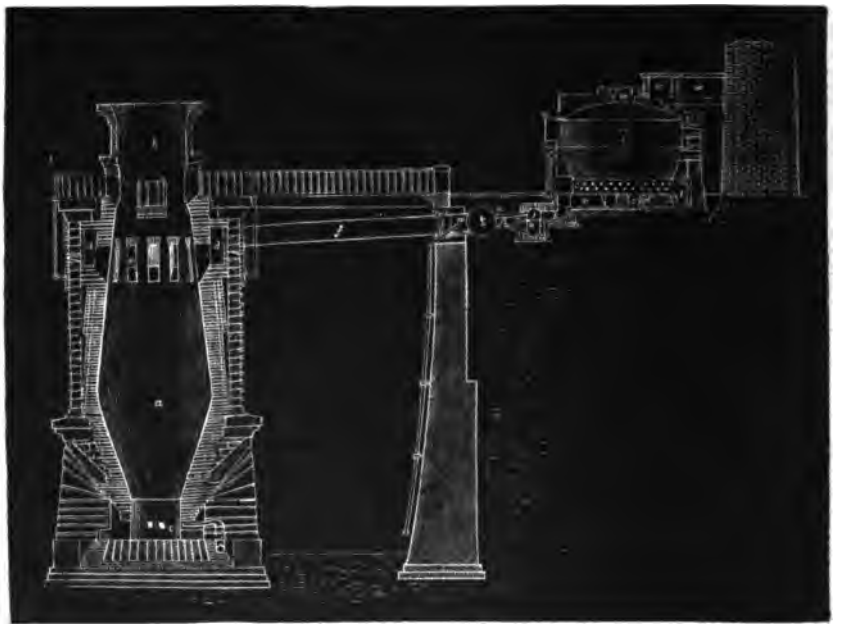


Fig. 135 shows the Coltness plan of drawing off the gases combined with a well-considered plan, invented by the late Mr. Jas. Hunter, for employing the gases to calcine iron ore and limestone. This plan is interesting not only from its being the first attempt on record in this country to calcine ore and limestone with gaseous fuel, but also because it worked very successfully for a considerable time. From our present knowledge of such subjects we can understand that as calcination was carried on at an even temperature—not exposed to the fluctuations produced by wind or rain acting on heaps—the quality of the ore calcined by gas was improved and a saving in calcining

Fig. 135.

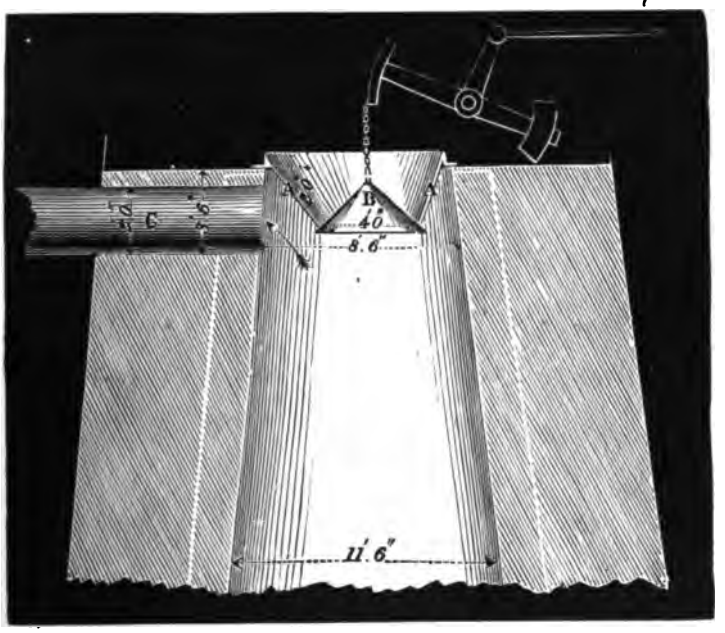


clay-band ironstone, amounting to *2s. 6d.* per ton of pig-iron produced from it, was effected. This saving was made up from the items of coal, dross, and wages. There were other incidental advantages; but when dross was very low in price it was found that the extra handling and carriage of the raw ore made it slightly cheaper to calcine with dross at the pits. There

is no reason, however, why this or a similar plan of calcining with gas should not now be carried out at the ironstone pits with gas generated from dross in gas producers. (Information as to gas calcining kilns will be found in "Iron," vol. 1879, pp. 163, 196, 227; also "Jour. Iron and Steel Inst., vol. i. 1882, p. 408; and in F. Kohn's "Iron and Steel Manufacture.")

In the Coltness plan, *a*, *b*, *c* is the section of the blast furnace, *d* being an annular space for collecting the gases into which *e* are ports or openings from the furnace lining. *f* is the branch pipe from *d* conveying the gases to the main *g*. *m*, *h*, and *p* are valves for regulating the supply and direction of gas and air, *j* is a combustion chamber (which in one modification is placed inside of the kiln itself), *o* being fire-bars; *k*, *r*, *s*, *l*, are passages for distributing the flame and hot gases, and *q* are passages also for that purpose. The waste gases pass off by the opening *u* and the flue *v* to the chimney *w*; *i* is the body of the kiln in section, *x* being charging

Fig. 136.



doors in the roof from trucks run over the kilns, and *y* are the doors by which the calcined mineral is removed.

In some of the Welsh furnaces, it was found useful to close, or partially close, the tops of the furnaces, for drawing off the gases more completely. Although the closing of the furnace has sometimes been found to interfere with the working, the plan was adopted at the Ebbw Vale and other works, without injury to the iron process. An inverted truncated cone *A* is suspended, as shown in Fig. 136, from the top of the furnace, the bottom truncated end being closed at will by a second cone *B*, the apex of which rises through the centre of the upper cone, and is attached to a central chain with an adjusting lever. When the lower cone is elevated, the gaseous escape is shut off, so that the current can only pass through the flue *c*. The furnace is fed by lowering the inner cone, when a fresh charge of fuel, &c., previously placed in the upper cone is delivered towards the sides of the furnace.

Fig. 137.

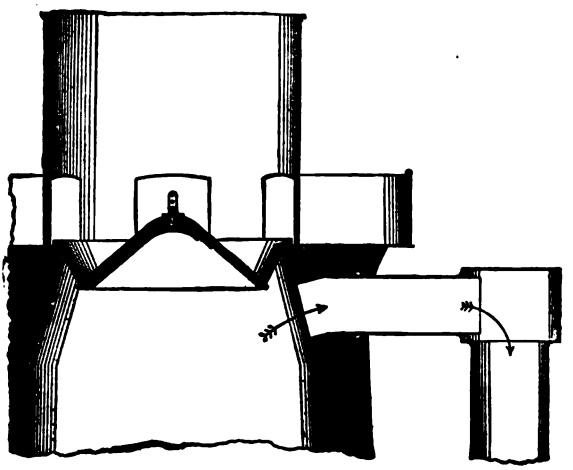
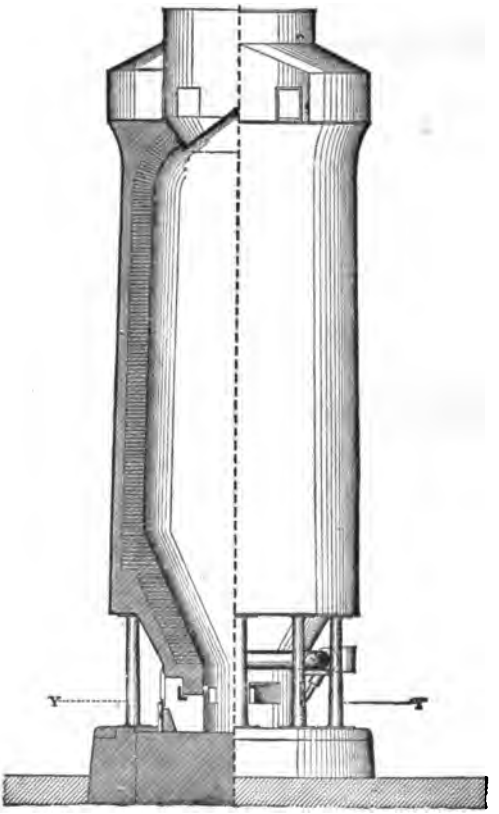


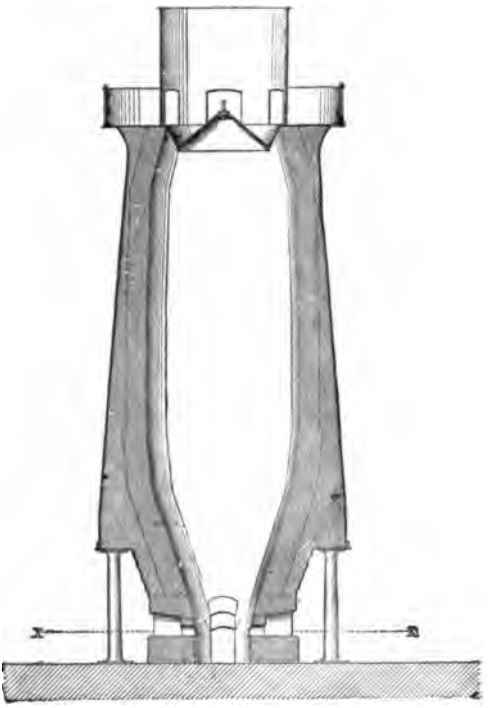
Fig. 138.



This is the general arrangement adopted in the Cleveland district, where open-topped furnaces have been almost, if not entirely, abandoned, and the bell-cone arrangement is also the one generally adopted where new furnaces are built or existing ones are altered to closed tops.

Fig. 137 gives a view of the modern form of this arrangement as carried out in Cleveland, and Figs. 138 and 139 show sections of some furnaces built in that district and elsewhere. The capability which good coke possesses of supporting a considerable crushing strain has enabled the iron-masters of that district to erect furnaces of great height and large cubical capacity. But after reaching sizes of 106 feet high and 33,000 cubic feet capacity, and 92 feet high, and 42,500 cubic feet capacity, it was found that economy of production does not increase with increased size beyond a

FIG. 139.



certain point, which it seems must be determined in each locality according to the nature and quality of the ore, fuel and fluxes, and the temperature of blast used.* The tendency latterly, therefore, has been to restrict the sizes to more moderate dimensions.

At Barrow-in-Furness and one or two other places the plan shown in Fig. 140 has been adopted instead of the bell-cone. This enables the level of the materials in the furnace to be seen, but although the side-passages for charging are open, yet as the level of the ore and other material charged is kept usually above that of the furnace crown, scarcely any gas escapes except by the central opening.

The gases after leaving the furnace are conducted in pipes or mains to

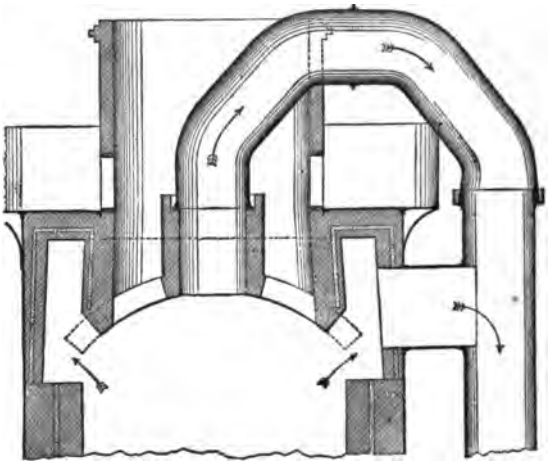
* See Grüner, "Studies of Blast Furnace Phenomena." Sir I. Lowthian Bell and J. Gjers, "Jour. Iron and Steel Inst." and "Proc. Inst. Mech. Engineers."

the hot blast stoves, and to the steam boilers, where they are ignited in contact with air. As will be seen from the analyses, they contain from 25 to 34 per cent. by volume of combustible gas, and are therefore very suitable for the production of the temperatures required in these applications of fuel.

Where coal is used in blast furnaces, a deposit of tar takes place on the cooling of the gases in the mains and branches, but with the introduction of methods of washing these gases both the tar and ammonia which they contain are, or may be, removed.

At Gartsherrie and other Works of Messrs. W. Baird & Co., extensive plant has been erected for this purpose, the method of operation being similar to that employed in gas works, where the gas is cooled by water to the temperature of the atmosphere, and a weak solution of ammonia in water is obtained.

FIG. 140.



At Summerlee Iron-works, the Messrs. Neilson wash the gases with sulphuric acid and water, forming sulphate of ammonia, which is stable at a comparatively high temperature in presence of water, and is crystallized out.

At Langloan Iron-works, the Messrs. Addie mix sulphurous acid gas with the furnace gases, and the compounds of ammonia which are thus formed dissolve readily in water even at a high temperature, so that great cooling of the gases is avoided.

In England, Messrs. R. Heath & Sons erected at their Norton Works extensive plant for the recovery of ammonia and tar by a modification of the plan used in gas-works, this modification being one patented by Mr. John Dempster.

These processes are fully described, with illustrations of the apparatus, by Mr. W. Jones in his paper on "The Recovery of Tar and Ammonia from Blast Furnaces."*

Composition of Blast Furnace Gases.—All the gases usually employed as fuel are mixtures of combustible with incombustible gases. The ingredients of the former class are carbonic oxide, hydrogen and a little marsh gas; the latter consist of nitrogen and carbonic acid, the nitrogen being almost wholly derived from atmospheric air. The gases vary in composition according to the part of the furnace whence they are taken: those taken immediately above the tuyères, where the consumption of the fuel is

* "Jour. Iron and Steel Inst.," No. 2, 1885, pp. 410–447.

complete, consist principally of carbonic acid, nitrogen and some hydrogen, the latter being derived from the decomposition of the aqueous vapour of the air in contact with the red-hot fuel. As this mixture ascends through other layers of red-hot coke or charcoal, the carbonic acid becomes converted into carbonic oxide, and higher still in the furnace, a reconversion of a portion of carbonic oxide into carbonic acid is effected by the reduction of the oxides of iron, which then mingles with the other products from the dry distillation of the fuel, and near the throat a large quantity of aqueous vapour forms part of the mixture. The temperature and pressure of the blast likewise influence the composition of the gaseous mixture.

Bunsen was the first to examine the composition of the gases from the blast-furnace, and those which formed the subject of his experiments were taken from the furnace of Veckerhagen in Hesse, in which wood charcoal was consumed as fuel. The following table exhibits their composition at different elevations above the tuyères:

Height above the Tuyères at which the Gases were collected	Composition of Furnace Gases in 100 Volumes.						
	5½ ft.	8½ ft.	11½ ft.	15½ ft.	14½ ft.	16½ ft.	17½ ft.
Nitrogen	64.58	61.45	63.89	62.47	66.29	62.25	62.34
Carbonic acid	5.97	7.57	3.60	3.44	3.32	11.14	8.77
Carbonic oxide	26.51	26.99	29.27	30.08	25.77	22.24	24.20
Marsh gas	1.88	3.84	1.07	2.24	4.04	3.10	3.36
Hydrogen	1.06	0.15	2.17	1.77	0.58	1.27	1.33
Total	100. 00	100.00	100.00	100.00	100.00	100.00	100.00
Quantity of oxygen in combination for every 100 vols. of nitrogen	29.8	34.2	28.5	29.6	24.4	37.3	33.4
Quantity of carbon-vapour for every 100 vols. of nitrogen	26.6	32.9	26.6	28.6	25.0	29.3	29.1

The furnace at Veckerhagen was 20¾ feet high from the tuyères to the mouth. The temperature of the blast during the time of collecting the gases ranged from 150° to 300° C. (300° to 572° F.), and the pressure amounted to 16 or 17 inches of water.

The gases evolved from a furnace at Clerval, in which wood charcoal was employed as fuel, were analysed with the following results by Ebelmen.

	Composition of Gases by Volume.					
Height above the blast	8 ft.	9½ ft.	13½ ft.	17½ ft.	22½ ft.	Furnace Mouth. 25½ ft.
Nitrogen	63.07	60.54	59.14	58.15	57.80	57.79
Carbonic acid	000	2.23	8.86	13.76	13.96	12.88
Carbonic oxide	35.01	3.64	28.18	22.65	22.24	23.51
Hydrogen	1.92	3.59	3.82	5.44	6.00	5.82
Total	100.00	100.00	100.00	100.00	100.00	100.00
Quantity of oxygen in combination to every 100 of nitrogen	27.8	31.0	38.9	43.1	43.3	42.7
Quantity of carbon-vapour to every 100 of nitrogen	27.7	29.6	31.3	31.3	31.4	31.5
Vapour of water to every 100 vols. gas	—	0.4	0.9	2.06	13.4	11.9

The height of the furnace at Clerval from the blast to the mouth was 25½ feet. The temperature of the blast was about 180° C. (356° F.), and the mean pressure 7.57 lines of mercury.

Scheerer and Langberg's examination of the gases from the Norwegian furnace at Bärum, where wood charcoal was also employed, gave the following results:

	Composition of Gases by Volume.					
Height above the blast . . .	10 ft.	13 ft.	15½ ft.	18 ft.	20½ ft.	23 ft.
Nitrogen	64.97	66.12	64.28	63.20	62.65	64.43
Carbonic acid	5.69	8.50	4.27	12.45	18.21	22.20
Carbonic oxide . . .	26.38	20.28	29.17	18.57	15.33	8.04
Marsh gas	0.00	1.18	1.23	1.27	1.28	3.87
Hydrogen	2.96	3.92	1.05	4.51	2.53	1.46
Total	100.00	100.00	100.00	100.00	100.00	100.00
Oxygen in combination to every 100 parts of nitrogen . .	29.0	28.2	29.3	34.4	41.3	40.7
Vapour of carbon to every 100 parts of nitrogen . . .	25.7	22.7	26.9	25.5	27.8	26.5

The furnace at Bärum was 28 feet high from the blast to the mouth. The temperature of the blast during the collection of the gases was between 200° and 300° C. (392°–572° F.), and the pressure 14 lines of mercury.

When furnace gases are employed as fuel, it is of course desirable to withdraw them from that part of the furnace where analysis shows the largest amount of combustible ingredients. This, however, could not be done without materially interfering with the process of reduction, for which the furnaces are employed, the carbonic oxide gas being the chief, if not the sole agent in reducing the oxide of iron to the state of metal. Theory and practice have both decided that the gases cannot be withdrawn without injury to the reducing process, at a lower level than about one-third of the height from the top; so that at Veckerhagen they might be taken at about 13½ feet, at Clerval at 17½ feet, and at Bärum at about 15½ to 18 feet above the blast. Above this level they become mixed with aqueous vapour, as was shown by Ebelmen's experiments at Clerval, and this reduces their heating effect. The gases capable of being advantageously used from the three furnaces will, therefore, have the following composition by volume:

	From the Furnace of			
	Vecker-hagen.	Clerval.	Bärum.	
			(I.) 15½ ft.	(II.) 18 ft.
Nitrogen	62.47	58.15	64.28	63.20
Carbonic acid	3.44	13.76	4.27	12.45
Carbonic oxide	30.08	22.65	29.17	18.57
Marsh gas	2.24	0.00	1.23	1.27
Hydrogen	1.77	5.44	1.05	4.51
	100.00	100.00	100.00	100.00

The composition of the gases from Veckerhagen and those from Bärum (I.), and those from Clerval and Bärum (II.), are so nearly the same, that a mean may be taken in afterwards calculating their relative values. Their mean composition by volume will be expressed as follows:

	A. Veckerhagen and Bärum (I.) Mean.	B. Clerval and Bärum (II.) Mean.
Nitrogen	63.4	60.7
Carbonic acid	3.9	13.1
Carbonic oxide	29.6	20.6
Marsh gas	1.7	0.6
Hydrogen	1.4	5.0
	100.0	100.0

This composition by volume corresponds with the following composition by weight:

	A.	B.
Nitrogen	63.4	59.7
Carbonic acid	5.9	19.4
Carbonic oxide	29.6	20.2
Marsh gas	1.0	0.3
Hydrogen	0.1	0.4
	100.0	100.0

The following results were obtained by Ebelmen, as the composition of the gases from the furnaces of Vienne and Pont l'Evêque, which are worked with coke as fuel.

	Composition of the Gases from the Furnace of Vienne.			
Height above the blast	2 ft.	17½ ft.	28 ft.	31½ ft.
Nitrogen	61.07	64.66	63 59	60.70
Carbonic acid	0.68	0.57	2.77	11.58
Carbonic oxide	36.84	33.39	31.83	25.24
Hydrogen	1.41	1.38	1.81	2.48
Total	100.00	100.00	100.00	100.00
Vapour of water to every 100 parts of dry gas	—	—	—	5.9
Vapour of carbon to every 100 vols. of nitrogen	30.7	26.4	27.2	30.3
Excess of oxygen over that contained in atmospheric air to every 100 parts of nitrogen	5.0	0.6	3.1	13.6
Amount of hydrogen to every 100 parts of nitrogen	2.3	2.1	2.8	4.1

	Composition of Gases from the Furnace of Pont l'Evêque.					
Height above the blast	½ ft.	1 ft.	2 ft.	10½ ft.	22½ ft.	33½ ft.
Nitrogen	75.10	71.20	62.70	64.47	62 72	62.47
Carbonic acid	8.11	5.87	0.16	0.17	0.68	7.15
Carbonic oxide	16.53	22.25	36.15	34.01	35.12	28.37
Hydrogen	0.26	0.68	0.99	1.35	1.48	2.01
Total	100.00	100.00	100.00	100.00	100.00	100.00
Vapour of carbon to every 100 of nitrogen	16.4	19.7	28.9	26.5	28.5	28.2
Excess of oxygen over that contained in atmospheric air for every 100 parts of nitrogen	4.4	2.4	2.8	0.7	2.8	7.9
Hydrogen to every 100 parts of nitrogen	0.3	0.9	1.6	2.1	2.4	3.2

The height of the Vienne furnace from the blast to the mouth was 31¼ feet, the temperature of the blast 220°–250° C. (428°–482° F.), and the pressure 0.04 millims. of mercury. The height of the furnace at Pont l'Evêque from the blast to the mouth was 33½ feet, the temperature of the blast 130° C. (266° F.), and the pressure 0.026–0.030 mill. of mercury. The parts of the furnaces from which the gases should be taken are respectively 20 feet above the blast in the former, and 22 feet in the latter. As no gases from that part were examined in the Vienne furnace, those taken at 17½ feet above the blast may be compared with the gases from Pont l'Evêque, a mean being taken between the two.

	Vienne.	Pont l'Evêque.	Mean.
Nitrogen	64.66	62.72	63.7
Carbonic acid	0.57	0.68	0.6
Carbonic oxide	33.39	35.12	34.3
Hydrogen	1.38	1.48	1.4
	100.00	100.00	100.0

This composition by volume corresponds with the following by weight:

Nitrogen	64.4
Carbonic acid	0.9
Carbonic oxide	34.6
Hydrogen	0.1
	100.0

Ebelmen subsequently made experiments at the furnace of Seraing, and corroborated the previous general results, the only difference consisting in a small quantity of marsh-gas, which was not estimated by the method of analysis adopted at Vienne and Pont l'Evêque. The analysis of these gases was performed by the eudiometric process, whilst the former were analysed by combustion with oxide of copper and direct weighing. Some doubt is, however, thrown by M. Cailletet (*Compt. Rend.* vol. lxxxv. p. 955—abst. "Proc. Inst. C.E." vol. lii. 364) on the correctness of the method employed by Ebelmen in his analyses of furnace gases. Cailletet contends that Ebelmen's plan of collecting the gases by slowly aspirating them through a long tube allowed combinations to take place which necessarily ignored phenomena of dissociation existing in the gases as given off from the furnace, and thus the results of the analyses really represented different gases from those given off. Cailletet obtained different results by cooling the gases rapidly.

	Composition of Gas by Volume from Furnace of Seraing.							
Height above the blast	1 ft.	34 ft.	36 ft.		37 ft.	42 ft.	45 ft.	
			I.	II.			I.	II.
Nitrogen	54.63	61.34	61.67	61.15	62.46	59.69	57.06	56.64
Carbonic acid	—	0.10	1.08	1.13	1.54	9.85	11.39	11.39
Carbonic oxide	45.05	36.30	35.20	35.35	33.88	28.06	28.61	28.93
Marsh gas	0.07	0.25	0.33	0.29	1.43	1.48	0.20	—
Hydrogen	0.25	2.01	1.72	2.08	0.69	0.97	2.74	3.04
Total	100.00	100.00	100.00	100.00	100.00	100.00	100.00	100.00
Oxygen for every 100 vols. of nitrogen	41.2	29.9	30.2	30.6	29.6	40.0	45.0	45.6
Vapour of carbon for every 100 vols. of nitrogen	41.3	29.9	29.6	30.0	29.4	33.0	35.2	35.7

The height of the furnace of Seraing from the blast to the mouth was 46 feet. The blast was heated to 212° F., and the pressure was 0.05 mill. of mercury. It will be observed that at the corresponding height above the blast, or at 34 to 36 feet in this furnace, as compared with the other two, the gases have very nearly the same composition.

The gases from iron-furnaces consuming coal as fuel have been examined at Alfreton, Derbyshire, by Bunsen and Playfair, at nine different levels. Their results were as follows:

Height above the blast.	2½ ft.	12 ft.	13½ ft.	16½ ft.	19½ ft.	22½ ft.	25½ ft.	28½ ft.	31½ ft.
Nitrogen	58.05	56.75	58.28	60.46	55.49	50.95	52.57	54.77	55 35
Carbonic acid	—	10.08	8.19	10.83	12.43	9.10	9.41	9 42	7.77
Carbonic oxide	37.43	25.19	26.97	19.48	18 77	19.32	23.16	20.24	25.97
Marsh gas	—	2.33	1.04	4.40	4.31	6.64	4.58	8.23	3.75
Hydrogen	3.18	5.65	4.92	4.83	7.62	12.42	9.33	6.49	6.73
Olefiant gas	—	—	—	—	1.38	1.57	0.95	0.85	0.43
Cyanogen	1.34	trace	trace	—	—	—	—	—	—
	100.00	100.00	100.00	100 00	100.00	100.00	100.00	100.00	100.00

The height of the Alfreton furnace from the blast to the mouth was 36¾ feet. The blast was heated to 626° F., with a pressure of 6.75 inches of mercury.

The most appropriate spot for withdrawing the gases from this furnace would be at about 22¾ feet above the blast, where the gases have the following composition:

Nitrogen	50.95
Carbonic acid	9.1b
Carbonic oxide	19.32
Marsh gas	6.64
Hydrogen	12.42
Olefiant gas	1.57
	100.00

The composition by weight corresponding with the above is as follows:

Nitrogen	56.3
Carbonic acid	15.2
Carbonic oxide	21.5
Marsh gas	4.2
Hydrogen	1.0
Olefiant gas	1.8
	100.0

The gases evolved from the anthracite furnaces at Ystalyfera were analysed at two levels by Schafhautl, with the following results:

Depth below the coal and mineral	16 ft.	1 ft.
Nitrogen	49.844	54.505
Carbonic acid	00.136	9.546
Carbonic oxide	18.974	12.012
Marsh gas	3.212	2.548
Hydrogen	27.844	21.278
Sulphurous acid, with traces of arseniuretted and phosphuretted hydrogen	trace	0.111
	100.000	100.000

The value of the escaping gases as affording an index of the working of blast-furnaces has been established by the labours of Sir I. Lowthian Bell, and has been fully illustrated in his writings on the subject and in

those of Prof. Grüner, C. Schinz and others.* The analyses quoted above have been examined in Sir I. L. Bell's writings in this light, and many others have been added by him, Mr. C. Cochrane, and other workers in that field, and the chemical and calorific phenomena have been so connected and shown in their relation to one another that it has become possible to calculate within narrow limits of error "the *technical* useful effect of any furnace and the *economical* effect of furnaces working in any district for which the proportions of fuel, ores and fluxes, and the temperature of the blast are known."

Grüner in his "Studies" has also emphasized the importance of ascertaining the proportion of carbonic oxide to carbonic acid present in the escaping gases of any furnace, and maintains that the ratio $\frac{CO_2}{CO}$ in these gases is the index of the working of the furnace.

It is impossible to give in a condensed form any satisfactory account of the voluminous researches and calculations which Sir I. Lowthian Bell has used in explanation and illustration of the complex phenomena of iron smelting; for these his own writings must be studied. He carefully measures the amount of heat generated in the furnace by combustion of the carbon, and conveyed into it by the heat of the blast, and apportions this heat in the amounts required by the several operations conducted by its means. In addition to these considerations, there are investigated the questions of the chemical combinations which take place between the carbon of the fuel and the oxygen of the blast, the carbonic acid formed by combustion and expelled from limestone, and the incandescent carbon, the carbonic oxide, and the oxygen of the iron ore; and the relations which these bear to the quantity and composition of the escaping gases and to the weight of materials delivered into the furnace.

As regards the one point of the ratio existing in the waste gases between the volume of the carbonic acid and that of the carbonic oxide which they contain, Sir I. L. Bell has said that his observations on the conduct of furnaces smelting Cleveland ore led him to conclude that, when the ratio is 1 volume of CO_2 to 2 of CO, the mixture of gases ceases practically to act on that ore. The largest average proportion of CO_2 he found was represented by 1 volume CO_2 to 2.09 vols. of CO, but, as a rule, fairly good working is obtained when the ratio is 1 vol. of CO_2 to 2:20 of CO.

The examination of various furnaces of different heights and sizes, and of their gases, ores, temperatures of blast, &c., has furnished data which lead to sound conclusions as to the requisite size of furnace for a given temperature of blast, the quantity of fuel required by ore of a given composition, and many kindred matters of importance. The part played in these investigations by examination of the chemical composition of the escaping gases cannot be over-estimated, and the result is that the index of the economical application of the fuel in the furnace is found in these gases.

The following, which is quoted from a comparison by Sir I. L. Bell between a blast furnace worked with raw coal and one worked with coke, illustrates the importance and usefulness of these investigations:

"The chief object of the present communication is to consider the differences between bituminous coal and coke in the smelting of iron, and to compare their respective action.

"If we measure the value of these two substances in a calorific point of view when both are fully oxidized, there is but little difference between them; the value being ascertained by the power possessed to raise the temperature of a given quantity of water.

* See, by Sir I. Lowthian Bell, "Chemical Phenomena of Iron Smelting;" "Chemistry of the Blast Furnace," "Jour. Chem. Soc.," 1860, "Jour. Iron and Steel Inst.;" Crookes and Röhrig's "Metallurgy;" Grüner's "Studies of Blast Furnace Phenomena;" C. Schinz, "The Blast Furnace."

"Full oxidization or complete combustion means, in the case of coke, the conversion of all the carbon into carbonic acid, and in the case of coal its conversion into carbonic acid and water.

"For the purpose of illustration, a specimen of coal from the Brockwell seam at a South Durham colliery will be taken; its calorific power will first be estimated in the raw state, and then a similar calculation will be applied to the coke made from the same coal.

	Composition of the Coal. Per cent.		Estimated Composition of Coke from the same Coal. Per cent.
Carbon	81.47	...	92.44
Hydrogen	4.57	...	—
Oxygen	5.04	...	—
Nitrogen	.91	...	—
Water	.76	...	—
Sulphur	1.22	...	1.00
Ash	5.51	...	6.56
	100.48	...	100.00
Fixed carbon	72.89	...	92.44
Volatile above 100° C. (212° F.)	20.84	..	nil
Volatile below 100° C.	.76	...	nil

HEAT DEVELOPMENT FROM EACH UNIT OF FUEL.*

	Coal.		Coke.	
Carbon to carbonic acid	.8147 × 8000 = 6518	calories,	.9244 + 8000 = 7395	calories
Hydrogen to water	.0457 × 34000 = 1554	,,	nil	,,
Total developed	8072	,,	7395	,,
Deduct heat absorbed by expulsion of hydrocarbons, &c. (including deficiency in heat development of C and H through combined O)	.2084 × 2000 = 417	,,	nil	,,
Net heat development	7655	,,	7395	,,

"By these computations it will be remarked that practically the heating power of coal and coke of the composition just given is the same, and the following are the results of a trial recently made on the North-Eastern Railway:

"Two lengths of road were selected on the North-Eastern system for the experiments. The same engines were used at both localities in the two sets of experiments; the trains consisted of the same number of waggons in the trials of coal and coke, and the loads were practically the same also. The trials were continued for one week with each kind of fuel, full loads being taken to the place of shipment, and the waggons returned empty to the collieries.

	Coal.		Coke.
One week's trial of each fuel; pounds consumed per train mile	40.5	...	41.6
One week's trial of each kind of fuel; pounds consumed per train mile†	37.0	...	42.2

"The parity of results observed in burning coal and coke on a grate where the combustion is, generally speaking, perfect, is not to be found in blast furnace experience, for the simple reason that the volatile constituents

* No credit is taken for the heat evolved by the combustion of the sulphur in either case, because the exact form in which it exists was not determined. Besides this, the heat evolved by the oxidation of sulphur is very small, and consequently its omission does not seriously affect the calculation. The water in the coke is also neglected, but this at Durham is also very insignificant in quantity.

† The coal in this trial contained only 1.2 per cent. of ash against 7.4 per cent. in the cok In both trials the coal and coke were from the same colliery—viz., Eldon and West Wylam.

are scarcely at all oxidized in the furnace, and consequently little or no useful effect is obtained from their presence. This statement presupposes that the smelting operation is conducted in a close-topped furnace; but in cases where the escaping gases are not utilised, the combustion on the mere upper surface of the materials is attended with little or no benefit.

"There is, however, another way in which the volatile hydrocarbons might be useful in the blast furnace—viz., as a means of reducing the oxide of iron to the metallic state.

"Reverting for a moment to the action of a blast furnace using coke, this first stage in the operation of smelting iron may be performed by one of two processes. Carbonic oxide generated by the combustion of carbon at the tuyères may be the reducing agent, in which case carbonic acid is the product; or else the operation may be effected by solid carbon, in which case carbonic oxide is generated. In the latter case, not only does the carbon which has served for the purpose of reduction never reach the tuyères, and in consequence acts no part in fusing the iron and slag, but since the heat generated by a unit of carbon leaving the furnace as carbonic oxide and as carbonic acid is respectively as 2400 to 8000, there is a great loss in the heating power of the fuel employed.

"The statement just made is, of course, an argument for seeking to obtain as large a proportion as possible of carbonic acid in the escaping gases. Experiment and practice, however, have demonstrated that the power of carbonic oxide to reduce an oxide of iron to the metallic state has its limits; and that when something like one-third of this gas is saturated with oxygen, *i.e.*, has become carbonic acid, further change is suspended. We have then the carbon gases in their ultimate form composed of one volume of carbonic acid and two volumes of carbonic oxide. It might, however, be possible to dispense with a portion of the carbonic oxide, and still maintain the reducing power of the mixture by substituting for it a gas also capable of deoxidizing the ore. The hydrocarbons, like the oxide of carbon, are energetic reducing agents; but it will be seen by a study of the composition of the escaping gases, as well as by a consideration of the quantity of fixed carbon present when raw coal is used in the blast furnace, that they do not render any marked service in the process itself.

"I have been permitted to examine with all the necessary care the working of blast furnaces using the celebrated splint coal of the Lanarkshire coal-field. The information thus obtained I propose to employ for the purpose of illustrating the subject of the present paper, selecting for this purpose the performance of a furnace having a height of 74 feet, and blown with air having a mean temperature of 800° F. (427° C.).

"Numerous specimens of the coal itself were collected, so as to obtain an average sample. This, as well as average samples of the escaping gases, were carefully analysed in the Clarence laboratory, and I would first direct attention to the composition of the coal as thus ascertained:—

ANALYSIS OF SCOTCH SPLINT COAL.

	Per cent.				
Water given off at 100° C. (212° C.)	11.62				
Carbon	66.00	namely, 53.41	fixed,	and 12.59	volatile
Hydrogen	4.34			4.34	,,
Oxygen	11.09			11.09	,,
Nitrogen	.94			.94	,,
Sulphur*	.59			—	
Ash	5.42			—	
Total	100.00	Matter volatile above 212° F.		28.96	,,

* A portion, probably one-half, of the sulphur is volatile; but in the calculation this is neglected.

"As a source of heat, the chemical composition of this coal indicates a great inferiority as compared with the analysis of South Durham coal. Instead of 81.47 per cent. of carbon and 4.57 per cent. of hydrogen, it only contains 66.00 and 4.34 of these substances respectively. Again, while the English coal only shows .76 of water and 5.04 of combined oxygen, we have in the Scotch 11.62 of the former and 11.09 of the latter. Computed in the manner applied to the South Brancepeth coal *ante*, the heating power of the Scotch splint stands thus:—

Carbon to carbonic acid	.6066 × 8,000 =	[illegible]
Hydrogen to water	.0434 × 34,000 =	1470
Gross heat developed		6756
Expulsion of water	.1162 × 540 = 63	
Expulsion of hydrocarbons, &c. (including deficiency in heat development of C and H through combined O)	.2896 × 2000 = 578	
		641
		6115

It thus appears that the South Durham coal possesses nearly 32 per cent. more of heating power than the splint coal just referred to.

"In order to estimate the manner in which this coal performs its work in the blast furnace, specimens of gas were collected over a period of three hours, so as to secure a sample of average composition. At the same time the moisture was determined, some cubic feet of gas were specially treated for the estimation of ammonia and tarry substances. The following figures contain the results of analysis by volume and by weight:—

		By Volume, per cent. of Dry Gas.	By Weight, per cent.
Carbonic acid	CO_2	6.29	9.66
Carbonic oxide	CO	29.04	28.36
Light carburetted hydrogen	CH_4	2.84	1.59
Heavy " "	C_2H_4	.24	.23
Hydrogen	H	6.83	.48
Nitrogen	N	54.63	53.34
Ammonia	NH_3	.13	.07
Water		—	6.27
		100.00	100.00
100 volumes CO are accompanied by volumes CO_2		21.53	—
100 volumes CO, CH_4, C_2H_4 and H are accompanied by volumes CO_2		16.06	—
Carbon in carbonic acid by weight is			2.63
Carbon in carbonic oxide by weight is			12.15
Proportion of C as CO_2 to C as CO by weight is as			1 to 4.62

"The consumption per 20 units of pig iron was as follows:—

	Units.
Raw coal in the furnace	42.39
Ironstone	37.46
Limestone	10.93

The average of fourteen observations, taken over a period of three hours, showed the escaping gases to have a temperature of 190° C. (374° F.), while the blast averaged 427° C. (800° F.).

"The carbon delivered to the furnace per 20 units of iron was as follows:—

Fixed carbon in the coal used		22.65
Carbon in the hydrocarbons		5.34
„ limestone		1.31
		29.30
Deduct carbon absorbed by pig iron	.70	
„ in tarry matter condensed	1.38	
		2.08
Carbon in escaping gases		27.22

"From these data the weight of the escaping gases per 20 units of iron have been computed to be as follows:—

		Carbon.	Oxygen.	Hydrogen.	Nitrogen.
Carbonic acid	16.26 =	4.43	11.83	—	—
Carbonic oxide	47.73 =	20.45	27.28	—	—
Light carburetted hydrogen	2.67 =	2.01	—	.66	—
Heavy „ „	.38 =	.33	—	.05	—
Hydrogen	.81 =	—	—	.81	—
Nitrogen	89.77 =	—	—	—	89.77
Ammonia	.11 =	—	—	.02	.09
Water	10.55 =	—	9.38	1.17	—
	168.28	27.22	48.49	2.71	89.86
Tarry matter	1.56	1.38	.03	.15	—
	169.84	28.60	48.52	2.86	89.86

"The quantity of heat evolved and appropriated is ascertained by the following calculations, while for the purpose of comparison there are placed alongside these figures those which express the duty performed by a furnace using 22.32 units of coke when smelting Cleveland calcined ironstone, the actual carbon in the coke employed being 20.40 units:—

	Raw Coal.		Coke.
Fixed carbon consumed per 20 units of iron, viz., that in 42.39 units of raw coal containing 53 41 per cent. = 22.65 and in coke 20.40	22.65	...	20.40
Deduct carbon carried off with an equal weight of carbon in limestone	1.31	...	1.64
Leaves carbon to evolve heat . . . . . Units	21.34	...	18.76

HEAT EVOLVED.

	Calories.	Calories.
Burning the above fixed carbon to carbonic oxide gives	21.34 × 2,400 = 51,204	18.76 × 2,400 = 45,024
Of this C as CO, the part oxidized to CO_2 gives	4.43 × 5,600 = 24,808	6.52 × 5,600 = 36,512
Of the hydrogen the part burnt to water gives	.55 × 34,000 = 18,700	—
Heat contained in the blast	11,920	11.919
Total heat evolved	106,632	93,455

APPROPRIATION OF THE HEAT.

	Calories.		Calories.	
Class I.:—				
Fusion of slag	10,054	...	16,702	
Decomposition of water in the blast	3,162	...	2,720	
Expulsion of carbonic acid in the minerals	4,044	...	5,054	
Decomposition of „ „	4,192	...	5,248	
Evaporation of water in coal and ore	3,051	...	312	
Expulsion of 12.28 units of hydrocarbon from coal	24,560		—	
		49,063		30,054
Class II.:—				
Reduction of peroxide of iron	32,710	...	33,108	
Carbon impregnation	1,680	..	1,440	
Reduction of silica, phosphoric acid, and sulphuric acid, the respective bases being found in the pig iron	4,266	...	4,174	
Transmission through the walls of the furnace	5,487	..	3,658	
Fusion of the pig iron	6,600	...	6,600	
Carried off in tuyere water	1,818	...	1,818	
		52,561		53,798
Class III.:—Carried off in escaping gases		8,953	..	11,043
		110,577	..	91,895

"There is, it will be perceived, a certain discrepancy between the two sides of the accounts, the somewhat large amount of which, in the case of the furnace using raw coal, being most likely due to the factor adopted for heat absorption, due to the expulsion of the hydrocarbons, viz., 2000 calories per unit, which has so far not been determined with the desirable accuracy.

"I would now direct attention to the salient points of difference in the performance of the two furnaces. We have in the case of the one using raw coal a much less perfect oxidation of the carbon, and in consequence a much smaller evolution of heat. The calories or heat units due from this source are as follows:—

Raw coal	.	21.34 units gave	76,012 calories	=	3562 calories per unit of carbon	
Coke	.	18.76 „	81,536 „	=	4346 „	„ „

"The heating power of the carbon is, however, largely supplemented by the oxidation of .55 units of hydrogen, which affords by its combustion 18,700 calories. Taking the carbon (21.34 units) and this .55 unit of hydrogen, we have 21.89 units, giving 94,712 calories—equal, therefore, to 4327 calories per unit of carbon and hydrogen. All the heat evolved by the combustion of this hydrogen, and far more, is, however, absorbed in the act of expelling the volatile portions of the coal. Under the classified heads of appropriation there are 27,611 calories taken up by the evaporation of water in the coal and ore, and by the gasification of the hydrocarbons; and of this only 394 calories were absorbed in evaporating the water in the ore.

"The comparatively low temperature of the escaping gases—190° C. (374° F.)—may be taken as an indication of the large absorption of heat in the upper region of the furnace. In the furnace using coke the temperature of its escaping gases, instead of that just indicated, was as high as 332° C (630° F.).

"Mention has been made of the supposed necessity which exists of maintaining a certain excess of the reducing gases in the upper region of the blast furnace. The smallest extent to which this excess is practicable in smelting clay ironstone I have considered to be arrived at when one-third of the carbonic oxide has been converted, by the act of reduction, into carbonic acid. As there is no alteration of volume by the change of composition, the ratio of the two gases is one volume of the latter to two of the former, which means one part by weight of the carbon as carbonic acid to two as carbonic oxide. I arrived at this conclusion by finding that, when calcined

Cleveland ore was exposed for many hours to the escaping gases just as they left an 80 feet furnace, little or no reduction was effected.

"In the case of the furnace using raw coal, these limits are far from being reached; for in its escaping gases the proportion was 4.62 volumes of carbonic oxide to 1 of carbonic acid; or, including the hydrogen and hydrocarbons (also powerful reducing agents), the ratio was 6.22 volumes to 1 volume of carbonic acid.

"There are, however, other considerations connected with the action of the blast furnace, which may intervene long before the point of saturation with oxygen is reached, viz., the need for heat in the hearth itself for the fusion of the slag and iron, and such portion of the work as is delayed until that point is reached.

"Of the carbon introduced into the furnace, it may be assumed that none of that contained in the hydrocarbons reaches the neighbourhood of the tuyères. Hydrogen, however, the result of the decomposition of atmospheric moisture, is always present in the gases in that region, whether the furnace is using coke or raw coal. A specimen of this gas from the Scotch furnace using the splint coal we are considering had the following volumetric composition:—

Carbonic Acid.	Carbonic Oxide.	Hydrogen.	Nitrogen.	
1.40 ...	32.96 ...	2.60 ..	63.04	= 100

"With regard to the behaviour of the hydrogen itself, the extent to which this element has been introduced into the furnace per 20 units of iron is thus computed:—

	Weight, Units, Hydrogen.
Hydrogen contained in water of coal, viz., that in 42.39 units of coal, at the rate of 11.62 per cent. = 4.92 water, equal to	.55
Hydrogen existing as such in coal = 100 : 4.34 :: 42.39 : . . .	1.84
Assumed weight of hydrogen due to atmospheric moisture . . .	.08
" " water in ore	.08
	2.55
Hydrogen contained in the gases in various forms, as per analysis . .	2.86
Difference	.31

"The simplest way to compute the quantity of carbon arriving at the tuyères is to consider the quantity of carbonic acid which ought to be in the escaping gases, and compare it with what is actually there. The deficiency must have disappeared by having dissolved so much carbon and become carbonic oxide.

"In the case of the coke-fed furnace already referred to, it is estimated that the carbon as carbonic acid which ought to be found in the gases per 20 units of pig iron is as follows:—

	Units.	Units.
Due to the reduction of oxide of iron	6.58	
Due from decomposition of limestone	1.64	
		8.22
There was actually found in the gases (carbon as carbonic acid) .		6.52
Deficiency (carbon as carbonic acid) . . .		1.70
The fixed carbon in the coke per 20 units of iron was . . .		20.40
Deduct that carried off by carbonic acid being resolved into carbonic oxide		1.70
Solid carbon in hearth		18.70

"In the case of the Scotch furnace, using raw coal, we have the following numbers:—

	Units.	Units.
Carbon as carbonic acid, due to reduction of oxide of iron .	6.58	
" " from decomposition of limestone .	1.31	
		7.89
There was actually found of carbon, as carbonic acid in gases . .		4.43
Deficiency (carbon as carbonic acid) . . .		3.46
The fixed carbon in the coke per 20 units of iron was		22.65
Deduct that carried off by carbonic acid		3.46
Total carbon in hearth		19.19

"It will thus be seen that there is no great difference (less than half a unit) in the two examples as to the quantity of carbon which actually reaches the tuyères for fusing the iron and slag; and the difference may easily be due to the different conditions attending the operations.

"Now, why, it may be asked, should there be so much larger a disappearance of carbonic acid in the Scotch furnace than is observed in the English one? It should be observed that the latter had a height of 80 feet, while the former, which was 74 feet high, was found difficult to manage if filled to a greater extent than 85 per cent. of its working capacity. This difficulty arose from the contents hanging, no doubt owing to agglomeration set up by the coking of the raw coal.

"One of the sources of economy of a lofty furnace is the increased period of time during which the ore is exposed to the reducing agency of carbonic oxide, at a temperature below that which suffices to have carbonic acid decomposed by carbon. Such, I apprehend, is the cause of the disappearance of carbonic acid in the older furnaces used in Cleveland. Thus, while in one of 80 feet in height, we may have 6.52 units of carbon per 20 units of iron as carbonic acid, in a furnace of 48 feet there would be only 5.47 units.

"Such may have been the cause of the loss of carbonic acid in the Scotch furnace using raw coal; but I think it highly probable that its disappearance may be partly due to the presence of the hydrogen emitted by the coal. In justification of this supposition I venture to quote certain experiments undertaken with a view to throw some light on this question.

"One hundred parts of limestone, containing 43.61 per cent. of carbonic acid, were placed in a heated tube, and over it, during thirty minutes, a current of hydrogen was passed. At a temperature of bright redness about one-half the carbonic acid was resolved into carbonic oxide. The oxygen separated combined with the hydrogen, and the resulting water was found to correspond with the oxygen lost by the acid.

"This reaction, however, is not one which would account directly for a disappearance of carbon at the tuyères, but the watery vapours generated might react on the fuel, carrying off carbon, and again setting the hydrogen free. The main question, however, is to determine, as nearly as we can, the weight of carbon actually present in the gases at the tuyères. There are certain disturbing causes, which time prevents my entering upon at present, but which render this ascertainment one of some difficulty. An analysis was made of the gases of the Scotch furnace, with the following results:—100 volumes contained 1.40 of carbonic acid, 32.96 of carbonic oxide, 2.60 of hydrogen, and 63.04 of nitrogen.

"Adopting the nitrogen as the basis of computation—*i.e.*, 89.77 units by weight of this element as present for each 20 units of iron—the carbon present works out to 20.64 units for this quantity of iron, instead of 19.19, as computed above.

"As having a direct bearing on the question before us, let us assume (which we are safe in doing) that the combustion of the hydrogen and hydrocarbons contained in the Scotch splint coal would suffice for their own expulsion, and that of the oxygen and water, without any loss of the fixed carbon. According to the analysis, we should have from 100 parts of the splint coal, omitting the sulphur, 58.83 of coke (53.41 fixed carbon, 5.42 ash), of which 100 parts would contain 91.63 of carbon, .50 water, and 7.87 of ash. The quantity of heat required to smelt the iron made in the Scotch furnace, using the splint coal as coke, instead of raw coal, may be thus estimated:—

	Calories.	
Class I.:—		
Fusion of slag (same as formerly given) . . .	10,054	
Decomposition of water in blast (taken as before) .	3,162	
Expulsion of carbonic acid in minerals . . .	4,044	
Decomposition of carbonic acid in minerals . .	4,192	
Evaporation of water in ore and coke . . .	550	
		22,002
Class II.:—		
Reduction, &c., same as in preceding statement . . .	52,561	
Class III.:—		
Carried off in escaping gases, considered as having a temperature of about 450° C. (842° F.), say	9,000	
		83,563

"The heat evolved by burning 1 part of carbon to carbonic acid and 2.28 to carbonic oxide, with air heated to 427° C. (800° F.), is as follows:—

		Calories.
1.0	carbon to carbonic acid × 8000 = ...	8,000
2.28	„ carbonic oxide × 2400 = ...	5,472
3.28	. . . . .	13,472
Hence one unit of carbon gives $\frac{13,472}{3.28}$ = ...		4,107
Heat in blast, estimated per unit of carbon		480
Total heat evolved by each unit of carbon . . .		4,587

"Now the total heat required for the process, when using coked coal, is 83,563:—

Hence $\frac{83,563}{4.587}$ = ...	18.22 units of carbon per 20 units of iron.
Add to this the carbon found in 20 units of the iron	.70
Total carbon per 20 units of iron	18.92

"This 18.92 units is equal to 20.65 units of coke, containing 91.63 per cent. of carbon; but the coal actually used in the furnace (42.39 units per 20 units of iron) contained 22.64 units of fixed carbon, and was in consequence equal to 24.70 units of coke having the composition supposed.

"According to this view of the process, there is a distinct waste of 3.72 units of carbon (22.64 − 18.92) when using coal in the blast furnace in its raw state. It must be remembered, however, that the chief source of the loss arises from the lower quantity of carbonic acid found in the gases at the Scotch works, and that it has been found impracticable to employ furnaces sufficiently high to ensure as large a percentage of carbonic acid as when coke is the fuel employed.

"Be it also remembered that the computation just made deals with the question from a purely heat-evolving point of view, whereas it is the

commercial aspect of the two modes which must determine the selection made by the ironmaster.

"The 3.72 units of carbon, or say 4 units of splint coal, when reckoned as cwts., are not worth in the market above 1*s.* 6*d.* If it were sought to coke like coal before using it in the blast furnace, the interest on the money expended in ovens, and the wages, would amount to more than this sum for every 20 units (cwts.) of iron made.*

"In the blast furnace, when raw coal is used, a loss of fixed carbon has been shown to ensue by the solvent action on this substance exercised by carbonic acid. In the ordinary coking oven a similar waste takes place from another cause, viz., the unavoidable presence of atmospheric air in the oven itself. This takes place to the extent of about 10 per cent. of the fixed carbon in the coal; which loss represents on each ton of iron almost exactly that incurred in the blast furnaces when employing the coal in the raw state. This, of course, only adds to the greater economy stated to be derived from not having to make use of the fuel in the form of coke.

"There is a still further circumstance in favour of employing raw coal in smelting iron. We have seen that, whether coked or raw, in a heat-giving point of view, there is not much to choose between the two; that, while about 4 cwts. of coal per ton of iron are wasted by inferior oxidation in the furnace, the same quantity is lost in the coke oven. In the former case, however, we have, in addition to the inflammable carbonic oxide of the escaping gases, about 7 cwts. of combustible gases which are useful for other purposes; whereas, in the coke ovens, but a very small percentage of these remains over, after satisfying the requirements of the process of coking itself.

"Any comparison, however slight, between the use of raw coal and coke in the blast furnace, would be very imperfect unless some notice were taken of the recent experience in condensing the tar and ammonia given off by coal, whether it is distilled in the coke oven or in the iron furnace.

"There being few varieties of coal which can be used coked or raw indifferently in smelting iron, it is almost useless to compare the conduct of the same coal under the two named conditions. Under these circumstances, a comparison will be attempted by considering the elements of calculation as they present themselves to us in actual experience. For this purpose I will select the coking coal of South Durham, and contrast it as a source of ammonia and tar with the coal used raw in the Scotch furnaces.

"In such coke ovens as are employed for the purpose in question there is practically no waste of fixed carbon, the distillation being performed in a closed retort of fire-brick. If we assume that 22½ cwts. of coke are consumed per ton of iron, we have, according to the analysis of South Durham coal formerly given, a trifle under 30 cwts. of raw coal required to furnish the coke for each such ton of metal. Estimated from the figures in the analysis just referred to, for each ton of iron made the coke ovens will have to provide means for separating the tar and ammonia from about 7½ cwts. of gaseous matter.

"In the Scotch furnaces using raw coal the weight of the gases is, of course, very much larger, because, besides that they contain the volatile constituents of the coal, all the fixed carbon of the coal is burnt, which means a very large admixture of atmospheric nitrogen. Instead, therefore, of having 7½ cwts. of gases to deal with in the coke oven for each ton of iron made with the coke produce, we have almost exactly 170 cwts. In other words, and speaking roughly, instead of having 20,390 cubic feet of

* It is assumed that coal used in the raw state is suitable for the manufacture of coke, which is not generally the case. This, however, does not affect the main object of this examination.

gas to contend with, the furnace gases emitted by a furnace using raw coal will occupy about 260,167 cubic feet, or something like 13 times the space occupied by the volatile constituents of the coal in the process of coking.*

"Under such a condition of things, it is almost needless to say that the condensable products accompanying the distillation of 30 cwts. of coal in a coke oven must be more easy of collection than the same products from 42 cwts. of raw coal burnt in a blast furnace.

"Assuming that the ammonia, by far the most valuable of these products, owes its origin exclusively to the nitrogen contained in the coal, the two varieties of coal we are considering, South Durham and Scotch splint, are about equal in this respect; the former containing .91 and the latter .94 per cent. Inasmuch, however, as fully one-third more coal is used in the Scotch furnace than in the English, we have in the former case to deal with a proportionate increase in the ammonia-generating substance, viz, nitrogen. So far, however, as my inquiries lead me to form an opinion on the subject, there is no more ammonia and tar obtained from a ton of coal distilled by Sir J. W. Pease & Co. in the Simon-Carvés oven, than is obtained by the Messrs. Baird from the coal used in the blast furnace. This would, if true, indicate that the yield of ammonia is not affected either by the increased difficulty attending its condensation as it leaves the iron furnace, or by the known action of ammonia on oxide of iron.

"The sulphate of ammonia obtained in each case was about 20 lbs. per ton of coal distilled; the alkali of this was considered worth 2*s*. 3.84*d*., reckoning the sulphate as being worth £15 per ton. The tar was worth 1*s*. 10*d*., making together 4*s*. 1.84*d*. The labour and depreciation represent about 1*s*., leaving 3*s*. 1.84*d*., or say 3*s*. per ton of coal used as such.

"In the analysis of escaping gases from the Scotch furnace using splint coal, the amount of ammonia was such as to represent 12.32 lbs. of this alkali per ton of iron, or 5.81 lbs. per ton of coal. This corresponds very closely with the ammonia in 20 lbs. of the sulphate, which weighs 5.15 lbs.

"On the other hand, the quantity of nitrogen in the fuel employed is sufficient to generate about 27 lbs. of ammonia per ton of coal; so that 20 lbs. of sulphate of ammonia represents only about 19 per cent. of that capable of being yielded from the coal were all the nitrogen expelled. Mr. William Foster, in a paper read before the Institution of Civil Engineers, pointed out that the nitrogen in coal, when distilled in a close vessel, was thus disposed of:—

11 to 18 per cent. takes the form of ammonia gas or its compounds.
.2 to 1.5 per cent. ,, cyanogen.
48 to 66 per cent. remains behind in the coke.
21 to 36 per cent. is not accounted for.

"These results point, therefore, to the possibility that the present quantity of ammonia (20 lbs. of sulphate) obtained from each ton of coal may be susceptible of a considerable increase."

ANALYSIS OF GASES FROM ASKAM BLAST FURNACE.†

	By Volume per Cent.		By Weight per Cent.	
Nitrogen	54.51	...	52.59	
Carbonic oxide	34.97	...	33.80	(1)
Carbonic acid	8.36	...	13.47	(2)
Hydrogen	2.16	...	0.14	
	100.00	...	100.00	

* The volumes of the two sets of gases are calculated for a temperature of 0° C. (32° F.). If the temperature were about 480, which is more nearly correct, the volumes just given would be nearly doubled.

† "Proc. Inst. Mech. Engineers," July 1871.

(1) Equivalent to $\frac{6}{14} \times 33.80 = 14.49$ per cent. carbon, and
$\frac{8}{14} \times 33.80 = 19.31$ „ oxygen.
(2) Equivalent to $\frac{6}{22} \times 13.47 = 3.67$ „ carbon, and
$\frac{16}{22} \times 13.47 = 9.80$ „ oxygen.

As the quantity of carbon carried off in the escaping gases is thus 18.16 per cent. of their weight when dried, it follows that the total weight of the escaping gases per ton of iron made is $100.00 \times \frac{21.56}{18.16} = 118.72$ cwts. when dried. The ore charged into the furnace contained about 1.00 cwt. of water and the coke 0.58 cwt., making together 1.58 cwt. of water, which is simply evaporated and passes off as steam in the escaping gases. Their total weight per ton of iron made is therefore

	Cwts.	Nitrogen.	Oxygen.	Carbon.	Hydrogen.
Nitrogen	62.44	62.44	—	—	—
Carbonic oxide	40.13	—	22.93	17.20	—
Carbonic acid	15.99	—	11.63	4.36	—
Hydrogen	0.16	—	—	—	0.16
Steam (not decomposed)	1.58	—	—	—	—
Total cwt. of gases	120.30	62.44	34.56	21.56	0.16

Some investigations have recently been made by M. A. Jaumain, of the Providence Iron-works, Marchiennes, Belgium (and published in the *Annales des Mines*), which show that there is a considerable difference in the composition of furnace gases and in their temperatures when taken from the centre and from the sides of furnaces provided with several leading tubes. The following analyses are extracted by "Jour. Iron and Steel Inst." No. 1, 1882, from his observations.

The No. 2 Marchiennes furnace is provided with three lateral gas flues 2.6 feet in diameter, and a central one 3.3 feet in diameter, the latter furnishing almost as much gas as two of the former together. The temperature of the gas from the centre was 120° C. and from the sides 248° C.: the following being the analyses:—

CENTRAL.

	By Volume.	By Weight.	
Carbonic acid	13.34	19.47	$\frac{CO_2}{CO} = 0.98$
Carbonic oxide	21.60	19.90	
Nitrogen	65.05	60.83	

LATERAL.

	By Volume.	By Weight.	
Carbonic acid	9.40	14.03	$\frac{CO_2}{CO} = 0.59$
Carbonic oxide	25.20	23.50	
Nitrogen	65.40	62.47	

At the No. 1 Monceau furnace, with three Cowper hot-blast stoves, the temperature of the gases from the central gas-flue was 110° C. and from the lateral ones 268° C. Analysis yielded the following:—

CENTRAL.

	By Volume	By Weight.	
Carbonic acid	9.80	14.30	$\frac{CO_2}{CO} = 0.66$
Carbonic oxide	23.80	21.79	
Nitrogen	66.40	63.91	

LATERAL.

	By Volume.	By Weight.	
Carbonic acid	14.00	20.32	$\frac{CO_2}{CO} = 1.04$
Carbonic oxide	21.40	19.52	
Nitrogen	64.60	60.16	

Running with only two Cowper stoves the temperature of the gases from the centre and sides was 184° C. and 290° C. respectively :—

CENTRAL.

	By Volume.		By Weight	
Carbonic acid . . .	8.20	...	12.27	CO_2
Carbonic oxide . . .	25.40	...	23.90	CO = 0.51
Nitrogen	66.40	...	63.63	

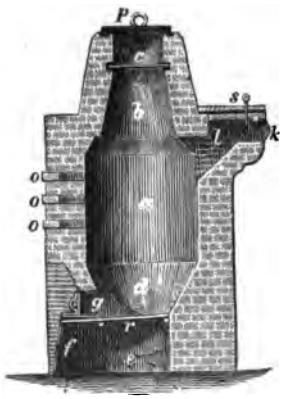
LATERAL.

	By Volume.		By Weight.	
Carbonic acid . . .	11.00	...	16.37	CO_2
Carbonic oxide . . .	21.40	...	20.00	CO = 0.87
Nitrogen	66.60	...	63.63	

Prof. Grüner has remarked that these and similar figures show that the marked difference between the gases taken from the centre and the circumference of a furnace makes it impossible to judge of its working, by either of them alone, and that observations of temperature and analyses have real value only when the gases are thoroughly mixed as they are in closed-top furnaces provided with a cup and cone.

Producers.—Special appliances for generating gaseous combustibles* are now extensively employed, and are of special value in localities where there is an abundance of almost valueless fuel, such as wood-shavings or sawdust, small charcoal and dust, turf, refuse lignite, and small coal or slack. The fuel is charged into these producers, which have been designed and made of various shapes and sizes, and the combustion is kept up with only the requisite amount of air for producing a maximum quantity of carbonic oxide gas. When charcoal and coke are used, the gases have been shown by Ebelmen to consist only of carbonic oxide and nitrogen, the latter being derived from the air; when wood, turf, brown coal, or coal is employed—or, in general, when the elements of water are present—carbonic acid, hydrogen and carburetted hydrogen are likewise found in the gaseous mixture.

FIG. 141.



Producers have been constructed either to work *with* or *without* a blast of air, and have been arranged variously with fire-bars or with solid hearths, and with or without openings for cleaning out the ashes or refuse from the fuel. In recent times, steam has been largely used along with the air passed in for combustion.

Bischof.—In Fig. 141 a producer without blast is shown, as used at Mägdesprung in the Hartz. The central part or body of the furnace *a* where the gases are generated is cylindrical, 5 feet in diameter and 5½ feet high; the upper part *b* and the under part *d* are conical, the upper 4½ and the under 2 feet high; *r* is a conical grate, below which is an ash-pit *e*, closed by an iron slab *f*. An aperture *g*, immediately above the grate, is capable of being closed by an iron door. When the damper *s* is raised, the gases escape by the port *l* into the square flue *k*, the upper part of which is constructed of iron plates, and covered with sand to retain the heat. The throat of the producer is separated from the body by an iron damper *c*, and the top is closed by an iron lid *p*. The space between *c* and *p* is

* Refer to "Min. Proc. Inst. C.E.," vol. lxxxiv. pp. 2–78.

just sufficient to hold one charge of the combustible matter with which the producer is supplied at intervals, and by withdrawing the damper *c* while the lid is in its place, the charge can be introduced without any escape of gas through the throat.

In working the producer, a layer of burning fuel, which we will assume to be charcoal, is thrown upon the grate *r*, and the whole furnace is filled up to *p* with the same material. The door *g* being closed, air enters below the grate through three apertures, 2 inches in diameter, in the slab *f*. The carbonic acid at first produced by the ignited charcoal (being in fact always the first product of the action of oxygen in carbon), on traversing the upper layers of red-hot fuel, soon becomes converted into carbonic oxide; and this gas in the upper regions of the generator being only mixed with nitrogen exerts no further influence on the fuel. The progress of combustion is under entire control by means of the damper *s* and the three apertures referred to, and can be observed through the holes *o o o*, which, when not in use, are closed by brick stoppers. The interior of the producer, as viewed through the lowest hole, should appear in a full glow; the combustion, as viewed through the middle hole, should be less intense, and no signs of ignition should be visible on a level with the uppermost hole; when this is not the case, there is danger of much carbonic acid being mixed with the carbonic oxide, and more fuel must be added, and the draught diminished. When turf, wood or coal is consumed in the producer, the carbonic oxide and nitrogen are naturally mixed with the tar-vapours, hydrocarbons, and other gases produced by the dry distillation of those substances. Some carbonic acid and aqueous vapour are also generated, and these tend to diminish the value of the gases as combustibles.

FIG. 142.

Ebelmen.—A producer intended to work with a blast of air is shown in Fig. 142, and was erected at the Iron-works of Audincourt, under Ebelmen's directions. In its general proportions, it resembled a small iron blast-furnace, the height from the hearth *b* to the throat being about 10 feet, the widest part above the bosses being 3 feet 4 inches, the narrowest part above the hearth about 10 inches, and the throat 13 inches. A cast-iron pipe descended from the throat about 4½ feet into the body of the furnace, and was kept constantly filled with fuel, which at Audincourt was small charcoal. A lid is only necessary when fuel in larger lumps is employed, the small pieces offering sufficient obstacle to the passage of the gases which find free passage into the space *q*, in which there is no fuel, and thence to the flue *k*. The blast is introduced at *f*. A much more abundant supply of gases can be obtained with producers of this construction than with the former, and the pressure of the blast being considerable, they can be conducted in a downward direction to the place of consumption; whilst, on Bischof's plan, the hearths on which they are to be consumed require to be placed nearly on a level with the exit-tube, which is at a considerable and often most inconvenient height, so that the bottom of the producer is often obliged to be sunk below the surface of the soil. One great obstacle to a regular supply of gas is occasioned by the fusion of the ash of the combustible to the sides of the furnace, as this diminishes the draught. This was partially obviatedby mixing, as at Audincourt, about 1½ part by volume of iron-furnace slag and clay with every 100 parts of combustible, which forms, with the ash, an easily fusible compound that can be run off

from the bottom of the hearth. If the charcoal is in the form of powder, a portion of this is carried over by the blast, and interferes, from obvious reasons, with the action of the gases. The condensation of the tar-vapours in the conducting tubes was also a source of annoyance, when uncharred fuel was employed. Great care is requisite in constructing these producers that no outlet be allowed for the carbonic oxide into the spaces occupied by workmen, as the effects of the gas are exceedingly injurious; and no ingress of air, except by the blast, must be permitted, or explosive mixtures of air and gas will be formed, which may produce the most serious consequences. It has been found expedient to subdivide the current of air as much as possible, in order to prevent any uncombined oxygen finding its way through crevices in the fuel to the mixture of gases in the upper part of the producer; the danger from explosion is thus diminished.

Ekman.—Another early form of gas producer (illustrated in Percy's Metallurgy) was invented by Gustav Ekman* of Sweden, and was successfully used there prior to 1845 along with gas furnaces which were also designed by the same intelligent ironmaster.

In Figs. 143, 144, the chamber for the production of the gaseous fuel, is built of fire-brick, and enclosed within a jacket of cast-iron, a free annular space being left between the two. In the fire-brick wall of the producer, there are two rows of tuyères, the upper one containing four and the

FIG. 143.

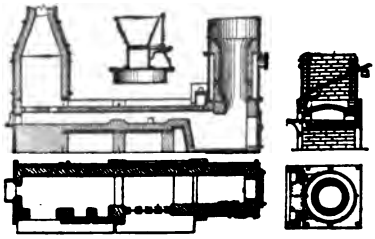
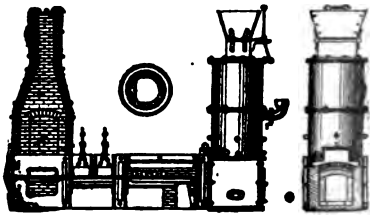


FIG. 144.



lower one three tuyères. In the iron jacket opposite the tuyères are small corresponding holes (fitted with moveable plugs) by means of which the interior of the producer may be inspected. A pipe in the iron jacket admits cold air at a pressure of about 1 inch of mercury from a blower into the annular space. The blast in its passage through this space becomes heated to from 90° to 150° C., the jacket and the wall of the producer being thus kept cool. On the top of the producer is a hopper, through which fuel is supplied by means of a sliding bottom, worked by a lever. At the bottom of the producer is an opening fitted with a door for the removal of ashes.

The producer communicates with the body of the furnace at the fire-bridge. In the roof of the furnace, on the producer side of this fire-bridge, is a series of openings, connected above with an iron box, which communicates with the blast space by two iron pipes, provided with stop-cocks. By this arrangement, a portion of the air entering through the blast-pipe passes into the interior of the producer, and another portion passes into the box, from which it descends through the openings. When the producer is filled with ignited fuel, and air is blown in through the pipe, carbonic oxide is copiously produced, which in its way towards the fire-bridge is met by descending jets of heated air entering through the openings in the roof, and is thereby effectually burned.

Wood charcoal was the fuel generally employed in this apparatus, and a very high degree of heat was obtained by its use. Peat artificially dried, but

* *Jern-Kontoret's Annaler* for 1850.

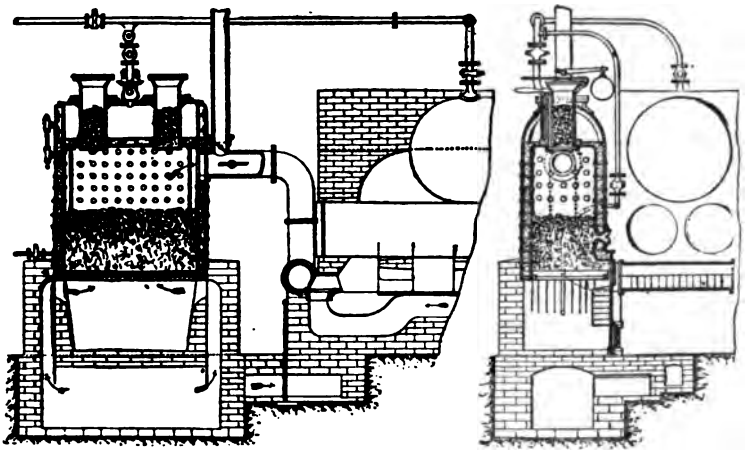
not charred, was also extensively used in such producers in Sweden. Caking coal is an unsuitable fuel for them, but anthracite might be employed provided that steam (by preference superheated) were injected along with the air in order to keep down the temperature in the body of the producer.

Beaufumé.—In the year 1856, an ingenious "Gasifier," the invention of M. Beaufumé, was introduced and tried by the French Government at the Imperial Arsenal at Cherbourg. The results of these trials, which were very satisfactory, were, with a description of the apparatus, communicated by the late Prof. Macquorn Rankine to the Inst. of Engineers in Scotland in Oct. 1857, and are published in the "Transactions," from which the following particulars are taken.

The "gasifier" is shown in longitudinal and transverse vertical sections in Fig. 145, and consists of a furnace, very like a locomotive fire-box in shape, having on all sides, except beneath the grate bars, a water space or water jacket, which prevents loss of heat by radiation, and in fact constitutes a small detached boiler raising a certain amount of steam.

This producer is filled with fuel to a considerable height, say 20 to 28 inches, according to the quality of the coal. The coal is introduced by two

FIG. 145.



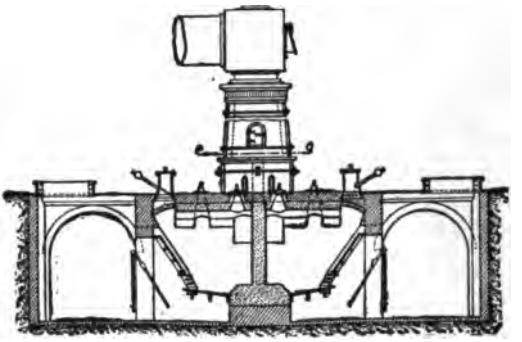
double-valved passages in the roof of the producer, and the following is the *modus operandi*:—When the outer cover of either passage is opened, the valve at the inner end is closed to prevent the escape of gas. The fuel having been introduced into the passage, the outer valve is closed, and the inner one being opened the fuel falls into the producer without allowing more gas to escape than the small quantity which fills the hopper or passage.

The proper quantity of air required for combustion in the producer is supplied by a blowing fan which forces it through the fire-bars. The air enters the ash-pit by apertures on opposite sides, and the carbonic oxide and other gases pass off by an outlet near the top of the producer and are conveyed by a pipe to the furnace.

The air to be mixed with the gases for their combustion is supplied by the same fan which supplies air to the producer, and is made to traverse a circuitous passage which is heated by the waste gases from the furnace. The producer gas issues from the pipe by a series of passages, arranged in a horizontal line at short intervals apart, while the air issues by alternate passages. By this arrangement, the air and gases become well mixed before combustion takes place.

Siemens.—About the same time Herr F. Siemens began to patent his ideas connected with regenerative furnaces, and these plans were introduced into Britain by his brother the late Sir C. William Siemens, who followed in the year 1861 * with a patent for a gas producer with a sloping grate and bars. This is the well-known Siemens producer, Fig. 146. The grate is evidently formed on the model of the "step-grate" which is used on the Continent, or on that of the "Chanter" grate, and this feature, with the introduction of a wrought-iron cooling-tube, constitutes the main novelty in the design of this producer. The cooling-tube generally commences at the top of a brick shaft or uptake placed above the producer at the back, and its object is to cool the gases issuing from the producer, thus giving them increased density, and causing an onward movement or current towards the furnace, and thus obviating the necessity of placing the producer at a lower level than that of the furnace. This cooling, however, introduced many annoyances through the condensation of tar, and modifications have been proposed in the producer and its working which were designed to obviate such difficulties. Mr. C. W. Siemens proposed to close the ash-pit by a door and force air in under the bars by means of an improved form of steam

FIG. 146.



injector, but the disposition of the grate in this producer, with its comparatively thin layer of fuel, prevents the success of a rapid combustion such as would be carried out by the proposed plan of forcing. The Siemens producer is, therefore, almost universally worked by means of a slow draught and the cooling of the gases.

Lundin.—An important addition to this producer was introduced by M. F. Lundin, of Carlstad Munkfors in Sweden, about the year 1863,† and consisted of chambers for cooling and washing the gas by sprays of water, and allowing it to pass over cooling tubes or other surfaces over which water trickled, in order to remove all traces of steam from it (Fig. 147). This enabled damp fuel such as sawdust to be used in the producer for the generation of gas which was to be used for producing high temperatures; and it also constituted M. Lundin the leader of the modern practice of washing producer gases.

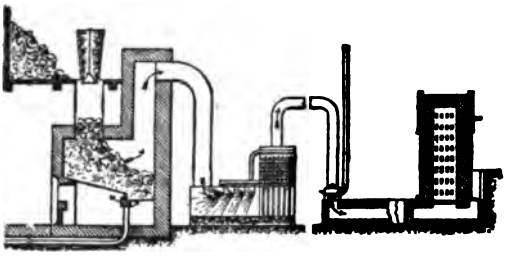
Berard.—M. Berard carried out a similar process in his own way as applied to the gas from a close producer of his own design; his object having been chiefly to remove sulphurous compounds and other impurities from the gas.

* In a paper by M. Turck entitled "Notice sur les Appareils Fumivores," &c., published in the *Mémoires de la Société des Ingénieurs Civils* (Oct. to Dec. 1866, No. 36, p. 585), Feb. 1857, is given as the date of the French patent for the Siemens producer.

† See F. Kohn's "Iron and Steel Manufacture," p. 142.

This producer was "a kind of cupola furnace, the principal feature of which was a movable bottom for the removal of clinkers." M. Berard proposed elaborate contrivances in order to prevent trouble from the clinkering of the ash and small breeze, which is always found a difficulty in producers worked with air blast alone.

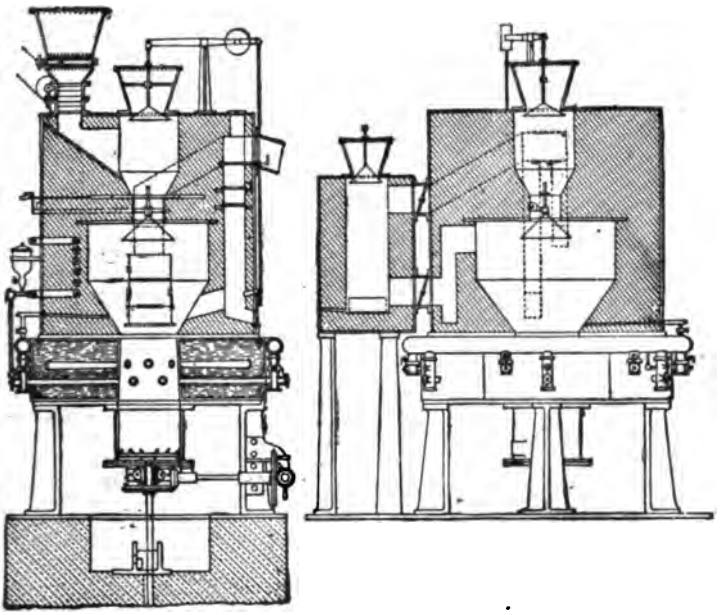
Fig. 147.



Benson.—A well-considered plan was introduced by Mr. G. H. Benson in 1868, and successfully worked under his direction for some months at Ironworks near Cleckheaton. He described it in a paper to the Iron and Steel Institute in 1869.

Fig. 148 illustrates the producer as used for free-burning or non-caking coal, coke, and peat.

Fig. 148.



It is a close vessel formed of a casing of wrought-iron plates with a lining of refractory material, and resting upon cast-iron standards about 6 feet from the ground. Fuel is charged either by a hopper and cone, or by mechanical feeding arrangements with rollers for breaking up large pieces, and the air required to support combustion is supplied from a fan or blower, and is carried from the main by separate connections to the tuyères which are placed in two rows at equal distances round the lower portion of the

producer. Hot blast is used, and steam superheated by a coil in the brick-work lining is also introduced at various points in the circumference at the same narrow portion near the bottom. This portion is formed of cast-iron boxes which contain water, this construction having been adopted in order to avoid the difficulty caused by ash and clinker adhering to brick sides of the producer at this point. The bottom of the producer is formed of a movable iron plate which is carried on a vertical iron support by means of which it can be raised, lowered, or revolved. It has a number of spikes on its upper surface in order to break up clinker, and agitate the mass resting on it. This plate is gradually lowered as the ash accumulates, and when at its lowest point the ash is removed by a door placed there. Openings are provided in the walls of the cast-iron box under the water boshes for

FIG. 149.

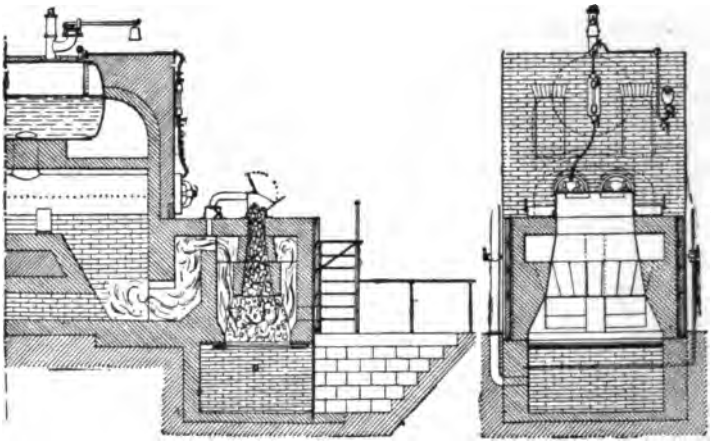
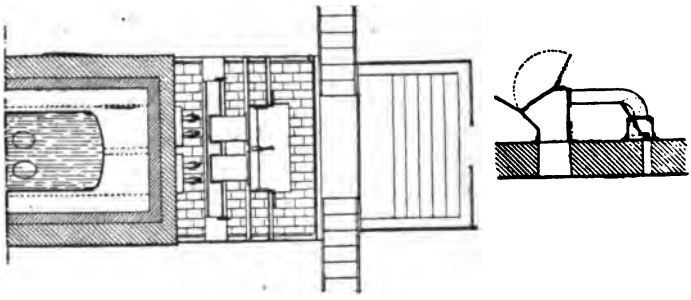


FIG. 150.



inserting bars to support the fuel in the producer while the ash is being cleaned out.

Passages and valves are provided by means of which the hydrocarbon gases containing tarry matters can be made to pass through the hot carbon in the producer in order to decompose the tarry hydrocarbons. In one arrangement Mr. Benson proposed to accomplish this "purification" of the gases by the use of a small subsidiary chamber containing coke, which was to be kept at a red heat by blast, and through which the gases could be made to pass on their way to the furnaces where they were to be consumed. This chamber is shown on the left of the right-hand section in Fig. 148.

Minary.—M. E. Minary of Besançon proposed in 1868 (*Publication*

Industrielle des Machines, outils et appareils, &c., Paris) two forms of gas producers, illustrated in Figs. 149–152, one having a flat grate with bars and a closed ashpit, Figs. 149, 150, and the other a closed brick bottom, Figs. 151, 152, in section like a gothic arch inverted, and having at the apex of the curves a tapping hole by which the melted ash and clinker were run out. Air blast was supplied under the bars into the closed ash-pit in one case, and from openings at an angle downwards from pipes running along two sides of the

Fig. 151.

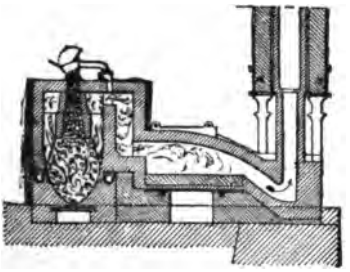
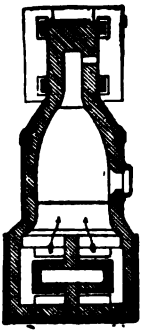


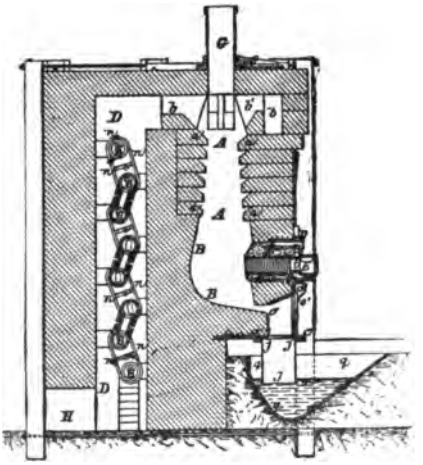
Fig. 152.



producer in the other case, and embedded in the brick-work near the bottom. Air was also introduced in both cases into the coal hopper, and down through the fuel. In the producer with grate bars, steam was also introduced under the bars.

Both producers were of rectangular form—like a flat-sided parallelogram—there being an inner rectangle tapering downwards from the charging hopper for about half the height of the producer carried by arches and surrounded by a chamber or space into which the hot gases escaped from the fuel, the object of this construction having been to heat the coal from the outside of this tapered portion. In order to fuse the ash in the producer with closed bottom, limestone was mixed with the fuel in proportions varying according to the amount of ash in the fuel.

Fig. 153.



In the discussion, in "Min. Proc. Inst. C.E." vol. 84, of a paper by F. J. Rowan on "Gas Producers," M. Minary contributed the following description of his new design with forced blast and fluid cinder which forms a modification of the producers just described.

Fig. 153 illustrates this apparatus, which is "based on the principles—first, of converting the fuel into gas, without losing the heat disengaged at the time of the production of the carbonic oxide on the first hearth; secondly, of volatilizing the hydrocarbons by the heat of the gaseous current from the first hearth; and, thirdly, of burning the gases in a combustion-chamber of fire-brick exempt from all contact with solid fuel,

the walls of the chamber attaining a very high temperature. This chamber has to be sufficiently roomy to allow of the gas occupying at least two seconds of time in passing through it, so that the reduction of its speed of transit causes the formation of eddies which induce admixture with the air let in from the top of the chamber. In this way, complete combustion is effected with only the volume of air strictly necessary, at the same time that the maximum temperature is obtained and all the heat due to the chemical composition of the fuel is set free. The apparatus is so designed that these operations are conducted automatically, the fuel being fed to the generator by gravity, as required to fill up the gaps produced by combustion and by the separation of the mineral and other refractory constituents of the fuel, the latter passing off after liquefaction by a small circular orifice *o* at the bottom. This liquefaction is obtained by the addition of limestone to the fuel, converting the refractory constituents of the latter into fusible silicates under the influence of the high temperature of the furnace. No attention is necessary beyond that of a man to charge the fuel to the hoppers at fixed intervals and to remove the slag, already broken up by falling into a water space below the hearth. The generator is of fire-brick having an interior compartment A A, of rectangular section, larger at the bottom than at the top, in order to facilitate, by spreading, the descent of the fuel. The walls of this chamber, instead of being flat, are formed of chamfered sections *a a*, in order to induce, during descent, the movement of the fuel from side to side alternately. The part immediately below this compartment B B forms the hearth of the producer. Its peculiar shape is designed to lessen the effect on its walls of the intense heat; at the bottom it is formed like a crucible, and it is furnished at one side with a small circular opening *o*, through which the liquid slag passes on its way to the water space *q q*. The hearth B B is furnished with one or more tuyères formed of tubing through which flows a current of cold water. The pipe E^1 conveys the blast previously heated by passing through the pipes E E. The chamber D D is rectangular throughout its entire height. It is traversed in the direction of its larger diameter by eight cast-iron pipes E E, arranged in a zigzag direction in order to baffle the outgoing current of producer gas and more effectually to heat up the air-blast in the pipes. At the bottom of the chamber D is an opening H, through which the gas passes away to the furnaces in which it is to be burnt. The producer is fed by the hopper G, made of sheet-iron, in cross section formed like a flattened ellipse."

M. Minary stated that he had successfully tested gas producers made on this plan, but that he purposed making some alterations with a view to working them with air blast less highly heated. "It has been found," he said, "that air heated to a very high degree does not suit the producer. The original disposition of the tubes heated the air to above 400° C. (752° F.), a temperature so high that the slag partially volatilized, and the result was that volatilized matters opposed the combustion of the gases in the combustion chamber. It was noticed that when the 'gasogene' was worked with an air blast exceeding 150° C. (302° F.), the pipes became white-hot, and the gases arriving from the combustion chamber instead of being clear and transparent were dull and opaque. Combustion no longer operated on the whole of the gas, but only on the upper strata, and the temperature of the remainder became stationary at a point below the welding-heat of iron. The resemblance remarked between these conditions and those of the cases of blast furnaces working grey highly carburetted iron led him to analyse the dust deposited under such circumstances from the producer gas: it was extremely fine and white. It contained silica, alumina, lime, magnesia and traces of iron, which were the elements constituting slag. When the heating apparatus was superseded by a single pipe delivering the air at 100° C. (212° F.) complete combustion of the whole gases was obtained, and a heat

produced in the combustion chamber sufficient for the welding of iron bars."

M. Minary also pointed out that this investigation explained how it is that the gas given off by blast furnaces working grey pig are feebly combustible.

Kidd.—In 1875, Mr. Joshua Kidd introduced a new form of gas generator (Figs. 154, 155), the purpose of which was to produce a modified water-

FIG. 154.

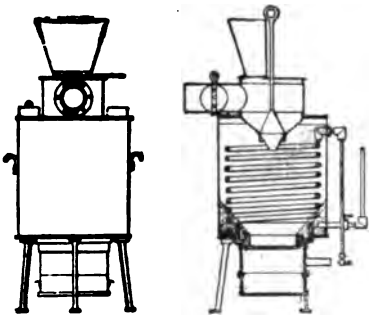
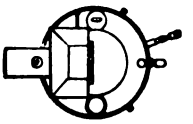


FIG. 155.



gas, principally for domestic heating and cooking. It consisted of a cylindrical chamber of iron standing vertically on three cast-iron supports, which enclosed a cast-iron cylindrical ash-pit, jointed in the middle so that the lower half could be detached for the removal of ashes. The only opening to the ash-pit during work was a pipe into which a jet of steam was blown, inducing a current of air along with it. This current of steam and air entered under movable grate bars upon which the fuel rested. With the exception of a small inclined ring of fire-brick lining at the bottom of the chamber just above the grate bars, the iron chamber was not lined, but had near its sides a coil of iron pipe for generating the steam required in working the apparatus. The fuel was fed in through a hopper with a conical plug in the top of the chamber, from which hopper a chimney branched off, having a damper. This chimney was for use in lighting up the generator until steam was produced. The gas exit was an opening in the flat part of the top of the generator.

Lowe and Strong.—Some very ingenious apparatus for producing a high quality of water-gas was introduced in America about the year 1874. There are two varieties of this apparatus designed for making illuminating and heating gas respectively, and these are known as the Lowe and the Strong apparatus, and they have been extensively adopted in America, besides having been introduced in England, in Sweden, and in Prussia with varying success.

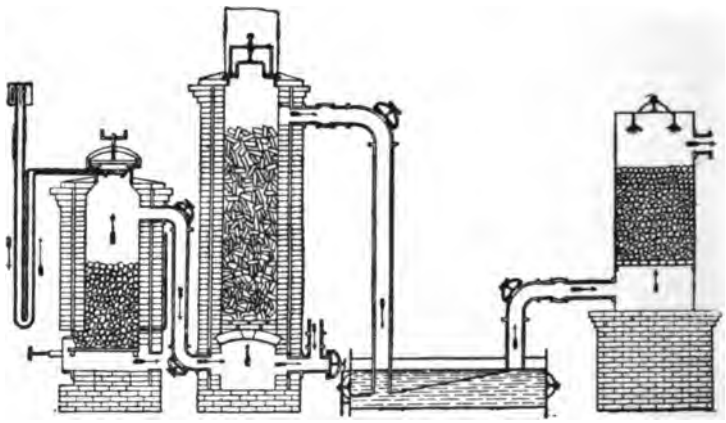
Much interesting information on the subject of these processes is to be found in a pamphlet issued by the Strong Gas Fuel and Light Co. of New York, and in a notice in "Engineering" of Nov. 14, 1879, while references to the English and German experiments are to be found in the "Journal of the Iron and Steel Institute."

The Lowe apparatus (Fig. 156) consists of a generator, a superheater, a washer or purifier and a scrubber, the generator and superheater being the essential and characteristic portions of the apparatus. These are in form like cupola furnaces, built of brick inside a casing of wrought iron, the superheater being about a half higher than the generator, and having a chimney or smoke-stack rising from its top. Near the bottom it has an air space or combustion chamber, formed by an arch which is perforated, and above the

arch the superheater is nearly filled with loosely stacked fire-bricks. A pipe connects the bottom of the superheater with the top of the generator, and another pipe, controlled by a valve, is provided to lead the gas from the top of the superheater to the purifier or the hydraulic main. An opening at the bottom is also provided for the admission of an air blast. There is a valve in the chimney by which it can be shut off at will. The generator has a charging door and valve at the top, underneath which the ends of some small pipes are inserted for the purpose of dropping oil upon the charge of fuel. At the bottom of the generator are grate bars and a closed ash-pit, into which an air blast is delivered. A pipe is provided for conveying steam into the hot fuel when necessary.

In working this apparatus, the generator is charged with anthracite, broken to the size of a large egg, through the opening in the top, which is then closed, and the valve to the chimney being open, while the gas outlet is closed, the coal is fired with the aid of an air blast under the grate. The gases formed by combustion, which are principally carbonic oxide and nitrogen, are driven off through the pipe to the chamber at the base of the superheater, where meeting an air blast they ignite and flame up through the mass of loose brickwork, which they gradually bring up to a white heat while the body of coal in the generator becomes cherry-red. This is the proper condition for gas-making. The valve is closed and the air blast shut off, the gas outlet is opened and at the same time steam, preferably superheated, is blown into

FIG. 156.



the mass of coal in the generator. In contact with the incandescent carbon the steam forms water-gas, consisting almost entirely of hydrogen and carbonic oxide, and at the same time small streams of crude petroleum are dropped directly upon the top of the red-hot coal, and becoming volatilized add hydrocarbon gases to the escaping water-gas. The mixture of gases passes to the bottom of the superheater, and thence upwards through the mass of white-hot brickwork to the outlet which conducts the gas to the washing apparatus, or to a hydraulic main. The action necessarily cools both the coal and the bricks of the superheater, but the superheating action completes the manufacture of the gas, and at the same time arrests any particles of carbon which may be carried over from the generator.

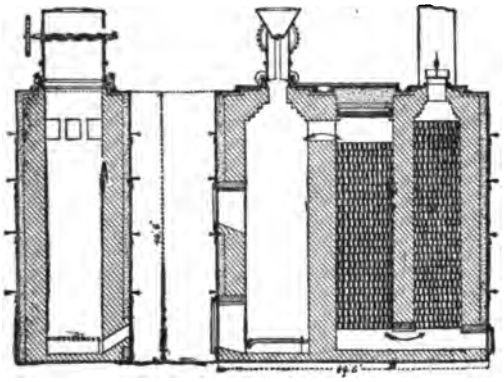
As soon as the temperature falls too low for proper admixture the supplies of steam and hydrocarbon are stopped, a little more coal is added to the generator, the blast is again turned on, and the process is recommenced.

It is claimed for this process that the superheater, which does not become

cooled so rapidly as the fuel in the generator, maintains a uniform and permanent composition of the resulting gas in spite of the changing condition of the generator, and that gases of lower density are produced by its means than by the retort system in use in gas-works.

The Strong apparatus for producing heating-gas is rather more simple, but also follows the intermittent method of working. The generator (Fig. 157) is also cupola-shaped, but has a greater height than that of the Lowe apparatus, and there are two secondary chambers or superheaters filled with bricks, regularly stacked as in a Siemens "regenerator." The generator is charged with coal or coke, and fired by an air blast admitted beneath the water-grate. The ascending gases pass through an opening near the top into the first superheating chamber, where they are met by a second air blast admitted through a perforated grating at the top of this chamber. The gases being ignited by this means, burn down through the brickwork of the first and upwards through that of the second superheating chamber, escaping by the valve and the chimney. By the time the coal in the generator is red hot, the bricks of the superheaters are nearly white hot. The air

FIG. 157.



blast is then shut off, the valve leading to the chimney is closed, and steam is admitted just underneath it. This steam becomes very highly heated and partially if not wholly decomposed in contact with the hot bricks as it passes in the reverse direction to the aforesaid gases, and as it enters the generator it is met by a shower of finely ground coal-dust which is fed from a hopper by an Archimedean screw. This coal is instantly distilled on coming into contact with the highly heated gases from the steam, and the resulting combination of gases is passed downwards through the red-hot fuel, which reduces the carbonic acid contained in them, and removes any undecomposed carbon; it is then conveyed away by an opening under the grate to the hydraulic main.

Several plans* have been proposed for rendering this class of apparatus more nearly continuous in working; one of the best of these was designed by Mr. C. Wittenström during the trials of the Strong apparatus in Stockholm in 1879. In this plan, there was a duplicate set of apparatus on each side of a central chimney, which was surrounded by a boiler for generating steam. The various steam, air and coal-dust valves for each set were combined together by means of levers which were all coupled to a main lever operating the chimney damper, so that by one movement each set of valves

* See "Min. Proc. Inst C.E." vol. lxxxiv. pp. 25, 26. Also *Stahl und Eisen*, vol. vi. pp. 3-13; *Zeitschrift des Vereines deutcher Ingenieure*, vol. xxix. pp. 800-801.

was simultaneously opened or closed along with either passage opening to the chimney. In another modification, Mr. Wittenström proposed to mount the superheaters vertically above the generators, placing a pair of combined chambers side by side, with a space between them filled up by tubes for generating steam; the gases from the superheater passing down through these tubes on their way to a chimney-flue placed underneath the whole apparatus. This arrangement allowed of a very simple method of working the valves by levers.

More recently, Mr. W. A. Goodyear ("American Institute of Mining Engineers," Feb. 1883) has proposed a plan with one generator common to two sets of superheaters (see "Jour. of Iron and Steel Inst." No. 1, 1883, p. 343), and another plan has been patented by the *Europeiska Wattengas Actiebolayet* of Stockholm (see "Jour. Soc. Chem. Ind." 1883, p. 370), whilst Mr. W. Crossley has patented a fresh arrangement (English patent, 1883—No. 589).

Water-gas Producers.—In spite of only partial success in Great Britain and in Sweden, the owners of the American (or Strong's) method of making water-gas introduced their plans into Germany, where they have led to important modifications, and ultimately to successful results.

The modified water-gas apparatus is due to Mr. E. Blass,* of Essen, and to Dr. Bunté, and was introduced by Messrs. Schultz, Knaudt, & Co. in their works at Essen.

The first successful apparatus introduced there had a working capacity of 10,000 cubic feet per hour, and consisted of a producer, two regenerators, a scrubber, and a gas-holder. The producer was cylindrical in form, having an iron jacket or casing, and an internal section like that of a cupola furnace, diminishing in diameter from about 50 inches at the top to 39 inches at about 8 feet from the top. At this point, a ring-shaped cast-iron water-trough formed a portion of the producer, and was supported on a short lower portion of the walls having a larger diameter than the upper part of the producer. From the water-ring downwards, the fuel, ash, and clinker spread out in conical form, leaving an annular space just below the water-ring, through which the blast and gas were alternately admitted and exhausted. Cleaning doors were arranged round the outside of this annular space, by which the refuse was periodically withdrawn.

The regenerators were cylindrical in form—one divided internally by vertical walls, like those in a Whitwell stove; and the other filled with chequer brickwork, like that of an ordinary Siemens regenerator. When first started, the producer was filled with suitable fuel and blown by the blast, the gas formed being ignited with air at the top of the producer, and the flame and hot gases conducted through the regenerator chambers, which they heated up. Subsequently, steam was introduced into these, and superheated on its way to the producer, through which it passed downwards, producing water-gas by reaction with the red-hot carbon. It was found, however, that fine particles of ash were carried over by the gas, and, in the high temperature produced by its combustion, they had a destructive effect on the brickwork of the regenerators. The method of working since then adopted has been to pass the gas generated in the producer (which is ordinary producer gas) through the regenerators, without igniting it, thus making use merely of its sensible heat there, and passing it either on to the gas-holder to mix with the water gas, or to boiler furnaces, where it is consumed in the usual way. In this way, the regenerators are not heated above 500° C., and the steam is therefore not highly superheated before passing through the coke. It has been found, however, that this change in the method of working

* *Stahl und Eisen*, vol. vi. 1886, p. 3; "Min. Proc. Inst. C.E." vol. lxxxiv. p. 499.

increases the yield of gas, shortens the period of blowing up, and lengthens considerably the life of the apparatus.

Several important details of the apparatus have been introduced by Mr. Blass and Messrs. Schultz, Knaudt, & Co., and several forms and sizes of the apparatus have been made. These are in use, producing gas used for working furnaces* for iron welding, and steel melting and heating, and also for lighting by means of incandescent burners composed of magnesia combs, invented by Mr. O. Fahnejelm.

The open-hearth steel-melting furnaces worked by this water gas require only one pair of regenerators, and work more rapidly than those using ordinary producer gas. The composition of the gas is—nitrogen 5 per cent., carbonic acid 4 per cent., carbonic oxide 41 per cent., and hydrogen 50 per cent.

Wilson.—What is now known as the "Wilson Gas Producer" was patented by Messrs. Brook and Wilson in 1876, but was introduced by Messrs. Howson and Wilson in connection with the Godfrey and Howson puddling machine at Middlesbrough. (See papers by R. Howson in "Jour. Iron and Steel Inst." No. 2, 1877, and "Engineering," Sept. 28, 1877.)

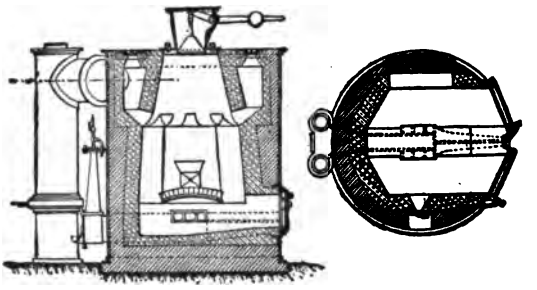
As first introduced, it was made rectangular on plan, and in vertical section had some resemblance to one of M. Minary's designs, which resemblance doubtless caused Mr. F. Lürmann ("Jour. Iron and Steel Inst." 1880, and "Engineering," Sept. 3, 1880, p. 200) hastily to assume that the plans were identical. The resemblance is, however, limited to the possession by both designs of a tapered upper portion of the interior into which the fuel is fed and which is, in Minary's case, only partly surrounded by a passage or chamber for the exit of the gases, whilst in the Wilson producer this portion is *entirely* surrounded by the chamber for hot gases. Both inventors had the same idea in view in this construction in as far as the intention was to impart heat to the freshly charged coal from the hot escaping gas, but in Wilson's case the purpose was that this upper portion should be a veritable retort in which the preliminary distillation of the fuel should take place, the gases from which should have to pass through hotter fuel on their way to the exit passages, so that they should be freed from the heavier hydrocarbons which readily deposit as tar in gas mains. In the Wilson producer, a novel method of supplying the blast was introduced as applied to a producer with a closed hearth without grate bars. This is a steam-jet, on the "injector" principle, entering the narrow throat of a tapered vertical pipe and inducing a current of air in proportion to the amount and velocity of the jet of steam. In practice, it is found that for satisfactory working the steam and air stand in the proportion of 1 of steam to 20 of air by weight.

The mixture of air and steam in this plan is conveyed into the interior of the producer by a raised channel, or "tuyère," laid across the centre of the hearth and pierced at the central point of the producer by three openings on each side of the tuyère. This method has the advantage of delivering the blast under pressure, so that the gas issues from the producer at a pressure of from 1 to 3 inches of water, and of delivering the blast at the farthest point from the walls of the producer, so that contact of both air and steam with the fuel is ensured. The decomposition of the steam abstracts heat from the ash, and renders clinkers brittle while preventing their melting and adhering to the brick sides and bottom of the producer, and the heat which becomes latent by the decomposition is recovered on the combustion of the hydrogen and carbonic oxide which it adds to the gases from the coal. This form of producer is periodically cleaned by hand by

* "Min. Proc. Inst. C.E." vol. lxxxi. p. 385, vol. lxxxiv. p. 503; "Jour. Iron and Steel Inst.," 1887.

means of doors opening on to the hearth at one side of the producer. Very soon after its introduction the rectangular form was discarded in favour of a circular one, Fig. 158, which permits of the whole producer being cased

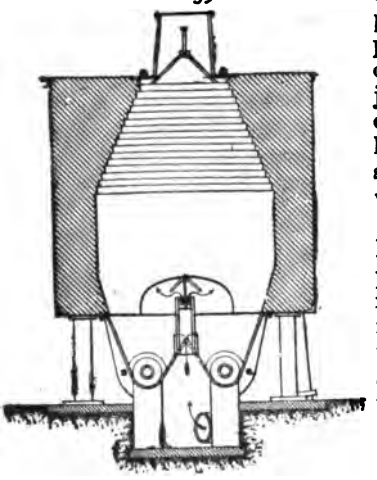
Fig. 158.



in wrought iron and adds to its compactness and durability. In this form, it has been largely used on account both of its compactness and of its speed of working, this latter being usually at the rate of 25.7 lbs. of fuel per square foot of hearth area per hour, as compared with 12.5 lbs. per square foot of grate area per hour, which is the usual rate for Siemens' sloping grate producers.

Since the introduction of these producers into America, several plans have been proposed there which contain the main features of the Wilson producer as applied generally to a producer with grate bars, such as the Philips producer and others, whilst the Langdon producer has a closed hearth, but introduces the air and steam from the steam jet through openings in the circumference of the lining leading from an annular passage which communicates with the steam jet,* this being found suitable for working with anthracite.

Fig. 159.



In a later patent (1882—No. 4697) Mr. Wilson has introduced a new form of producer (Figs. 159–161), which was the first, and for a time the only one providing for the automatic continuous removal of the ash and clinker by machinery. The same means are also applied to the continuous feeding in of the fuel from a hopper above, and, if desirable, motion may be given to the ironwork forming the entire bottom of the producer in order to agitate and break up the mass of fuel, and thus keep it regular and even in consistency. By these means, the necessity for manual labour for charging, poking the fuel, or cleaning out is entirely obviated. The discharging mechanism, consisting preferably of iron worm screws, works in troughs containing water, which forms a seal to that part of the producer, preventing the escape of gas even though a pressure of 6 inches of water is kept up in the producer, and this water also forms a recuperator of heat, because the ash and clinker having to pass through it impart their heat, which would

* See "Jour. Iron and Steel Inst.," vol. ii., 1883, and "Trans. Amer. Inst. Mining Engineers," June 1883.

otherwise be wasted, to it and issue by the shoot comparatively cold, whilst the water evaporated by the heat ascends as steam in the producer, and adds by its decomposition to the heating gas.

Some of the same features are found in a subsequent patent of Siemens (1883—No. 663) and in one of L. Mond (1883—No. 3821).

Fig. 160.

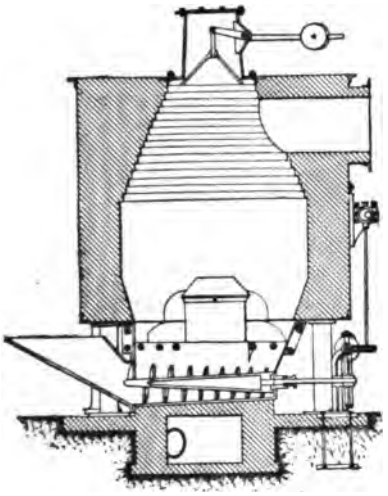
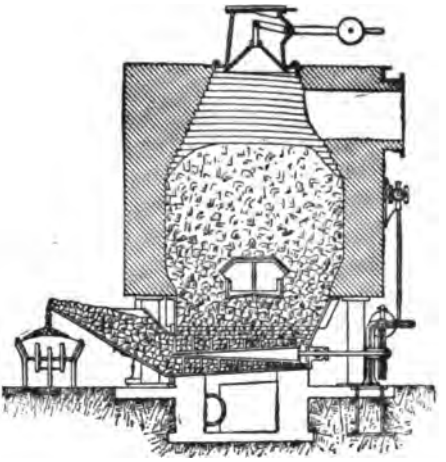
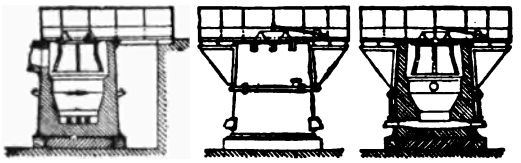


Fig. 161.



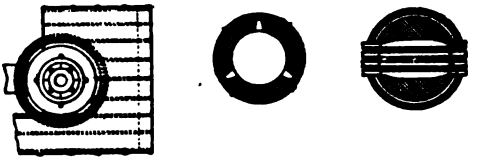
Tessié du Motay.—The gas producer with which the name of M. Tessié du Motay, a well-known French metallurgist, is associated was first brought prominently before the notice of engineers in this country and America by

Fig. 162.



the late A. L. Holley, LL.D.,* although it appears (from *Mémoires, &c., de la Société des Ingénieurs Civils*, No. 28, Oct. to Dec. 1874, p. 883) that it was known in France in 1871, and that some results of its working in Paris

Fig. 163.



and at Terrenoire were communicated to the French Institution of Civil Engineers. In a communication to that body in 1874, M. Lencauchez, however, disputes the accuracy of the results reported by MM. Tessié du Motay and Pourcel.

The producer as described by Holley (Figs. 162, 163) was a cupola-shaped

* "Trans. American Inst. Min. Engineers," vol. viii. p. 27; "Engineering," Dec. 12, 1879, p. 457.

furnace with closed hearth, built inside a wrought-iron cylindrical casing, the sides having different diameters at various portions of their height, and having one part built with an incline like the boshes of a blast furnace. Underneath the cup and cone charging hopper was hung a bell-shaped cylinder of wrought iron to direct the charge of fuel and leave an annular space at the top of the producer with which the branch pipe communicated. The producer was worked by air blast, a blast pipe encircling it at about half its height with branches leading down to four cast-iron boxes on each of two sides, which boxes formed the terminations of grooves or channels formed across the hearth for the accumulation of ash, clinker, and scoria. By opening any pair of these boxes connected with one groove, the refuse material could be pushed through from one side and discharged at the other. Any clinker adhering to the brickwork of the sides of the producer could not be dealt with by this method of cleaning, and this producer has the objection common to all producers worked by air blast, that of necessarily working too hot and producing a comparatively large proportion of carbonic acid in the gas. It seems from Holley's remarks that there was also some loss from coke being mixed with the ash, &c., in cleaning.

Practically the same plan, but with the addition of a steam pipe led into the blast boxes, was described by Mr. D. Cowan to the Mining Inst. of Scotland ("Transactions," vol. v. part 9, p. 335) as in process of erection in March 1884 at the Carron Ironworks.

Dowson.—A compact arrangement was patented and introduced by Mr. J. Emerson Dowson (1878—No. 3997 and 1881—No. 2859) for supplying gas for the smaller industries and for domestic purposes, and it has been successfully applied to the production of gas for working "Otto" gas engines. This producer (Figs. 164, 165) follows more in the line of that of

Fig. 164.

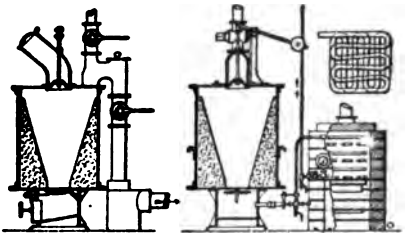
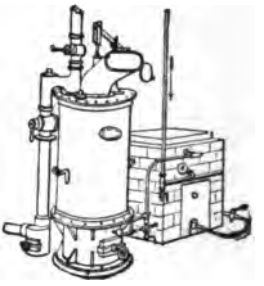


Fig. 165.



Kidd than in that of Wilson, but it differs from Kidd's generator in having the coil of pipe for raising or superheating the steam supply separate from the producer.

As described by the inventor, the apparatus consists of a generator with a cylindrical iron body, which encloses a thick lining of refractory material, as in a foundry cupola, to prevent loss of heat and oxidation of the metal. At the bottom of this cylinder is a grate, and on this the fire is built up. Under the grate is a closed chamber, into which a jet of steam plays, carrying with it by induction a current of air, and by reason of the pressure of the steam the mixture of steam and air is forced upwards through the fire. The steam is superheated before it enters the generator, and should have a pressure of 20 to 25 lbs. per square inch. The steam is produced and superheated in a zigzag coil of pipe enclosed in a separate superheater (or furnace). The coil is heated by some of the gas from the producer or from a gas-holder, except when starting the apparatus, and then a fire is lighted under the coil. A hopper is provided for charging the

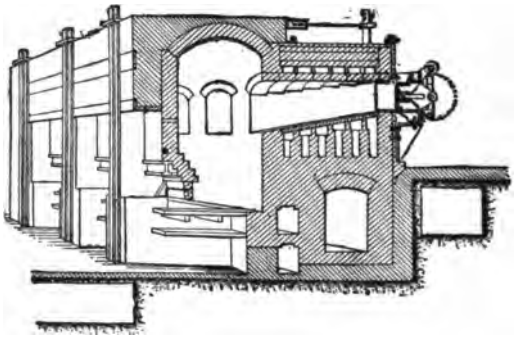
producer with fuel, and an exit pipe, also on the top surface of the producer, provided with a vertical branch to be used as a chimney at starting. The brick or gannister lining of the producer tapers downwards in a straight cone from the full diameter of the casing at the top to the small diameter of the movable grating at the bottom. For many heating operations, ordinary coal may be used in this apparatus, but anthracite is preferred. Purifying and washing appliances are usually combined with this apparatus as demanded by the purposes to which the gas is usually applied.

Gröbe and Lürmann.—Starting from the principle that a good gas producer should provide two distinct chambers, in which respectively the hydrocarbon gases should be expelled from the coal, and the resulting coke should be converted into gas, Messrs. Gröbe and Lürmann, in order to satisfy the demands of their theory, devised (in 1877) the producer which bears their name. In a communication to the Iron and Steel Inst. at their meeting at Düsseldorf in 1880, Mr. Lürmann claimed that "all generators constructed hitherto have only had one chamber in which the gases contained in the fuel are expelled, and the resulting coke is converted." "The green damp fuel," he said, "is charged, cold and unprepared, from time to time upon the materials which are in process of decomposition, similar to the process which takes place on an ordinary grate, and as the two processes of expelling and of converting require entirely different conditions, the quality and quantity of the resulting gases are constantly changing. To expel the gases contained in the fuel, no atmospheric air is required, but only heat, whilst for the conversion (combustion) of the remaining solid parts (coke) into carbonic oxide, atmospheric air is essential. It requires no heat, but, on the contrary, throws heat off, which is partly employed for expelling the gases from the fuel, and, having thus become latent, it cannot be utilized in the combustion chamber. With all firing arrangements in which high temperature is the object, it is of importance not to lose heat by radiation or conduction or to allow any of the heat to become latent." These statements, however, require qualifying, for in both operations, that of distilling the hydrocarbons from coal and that of volatilizing the solid carbon by transforming it into carbonic oxide, heat is *abstracted*, and so far becomes latent. It does not matter much whether that heat is supplied partly by the hot producer gases themselves, or wholly by additional supplies of heat, the amount required remains the same. Moreover, both the Minary closed hearth producer and that of Wilson are admitted by Mr. Lürmann to be possessed of distinct portions in which the two processes are carried out, but his objection to them takes the form that the expulsion chamber is not separate from the conversion chamber, but is an elevated part of it, and that the heat of expulsion is drawn from the heat produced by conversion, or more correctly by the combustion of some of the carbon to carbonic acid during conversion, and thus becomes latent. There is, moreover, no similarity between these forms of gas producers and an ordinary grate, for in the upper or "retort" portion of the producers the coal is heated from the outside without access of air, and therefore the difference between them and the Gröbe producer is merely one of degree.

In the Gröbe producer (Fig. 166), the chambers for the different operations are quite distinct, a horizontal chamber, which is heated from the outside by waste gases from furnaces which traverse the passages surrounding it, being provided for the distilling operation. One end of these horizontal chambers (for there are several placed side by side) opens into a vertical chamber, which extends along the row of horizontal chambers, and is provided with grate bars, into which chamber the red-hot coke is pushed from time to time. Passages are provided for heating the air supply for combustion, and the mixture of hydrocarbon gases from the horizontal chambers

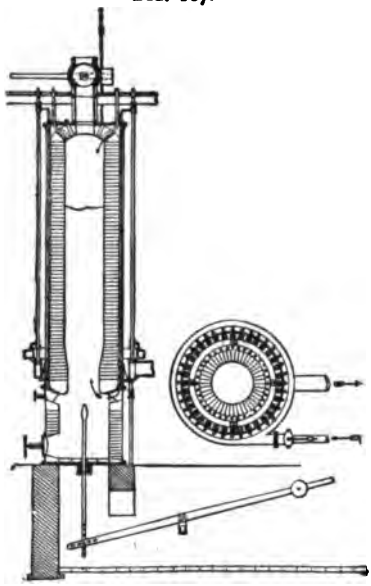
and carbonic oxide and nitrogen from the vertical chamber is withdrawn by a common exit tube from the latter. This gas producer is said to have worked with great regularity and economy and to have displaced the Siemens generators at the Osnabrück Steel Works.

Fig. 166.



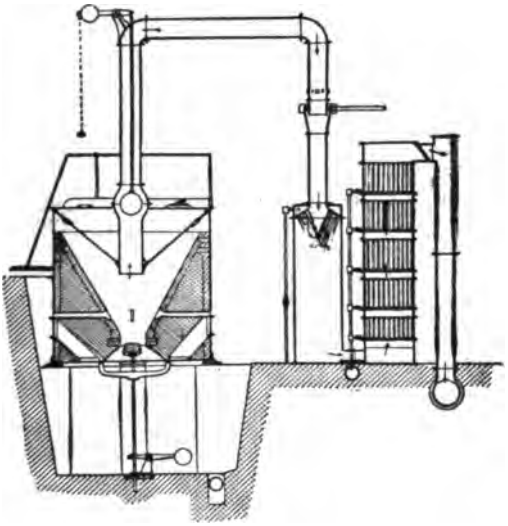
Sutherland.—Mr. W. S. Sutherland's first patent for welding by means of gas was taken out in 1869, but he did not patent a gas producer until 1874 (No. 1784). This producer (Fig. 167) was a tall cylindrical chamber formed by a metal casing with an annular space next it containing sand, in which space vertical tubes were placed to convey the blast of air for combustion down to another space formed by the brick lining of the producer. The brick lining came next the sand, and was built parallel at the top of the producer, then slightly inclined towards the centre just above the point where air was admitted, at which point the lining was widened considerably so as to form a broad annular opening for an air space—the lining above this sudden increase of diameter being held up by an iron ring fastened to the metal casing of the producer. Underneath the air opening the larger diameter of fire-brick lining was continued so as to form a chamber for the collection of ashes and refuse, which were periodically removed by a suitable door. A vertical iron poker was worked by means of a lever at the bottom of the producer to stir the fuel and break up clinker—the arrangement of this being similar to that in Benson's producer. A charging hopper was provided at the top of the producer, and there were numerous small iron pipes coming out radially through the top of the producer to convey away the gases; these pipes as soon as they dipped vertically downwards being enclosed in larger pipes conveying the blast from an annular blast-box or belt to the top of the producer casing, whence smaller blast pipes descended through the sand lining as described. The object in building this producer high was that the gases should be partially cooled by heating up fresh fuel, and it was intended that they should give up further portions of their heat to the air for combustion by means of the other arrangements, so that the

Fig. 167.



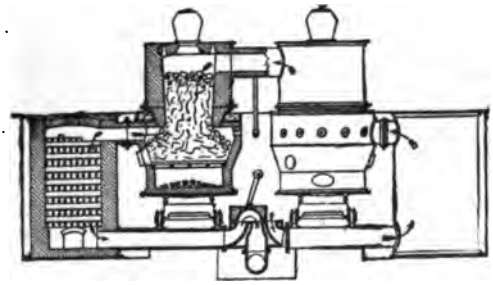
tarry and other matters should thus be removed before the delivery of the gases to the main. The dimensions and proportions which are, however, given to the pipes and passages for the producer gases, and for the removal of "water and surplus tar" from the gases, would argue that this arrangement of producer, whatever its merits, could not have been constructed and worked as it is shown on the patent drawings. In 1878 (No. 3274), in 1882 (No. 3908), and in 1884 (No. 8053), Mr. Sutherland patented improved forms of his gas producer, these having a larger diameter compared with

Fig. 168.



their height, and being provided with either a movable plug or valve or grate-bars at the bottom. Some of these forms of producer are intended to be worked by having the gases withdrawn by exhausting appliances in order to pass them through condensers and washers (Fig. 168), but one form (Fig. 169)

Fig. 169.

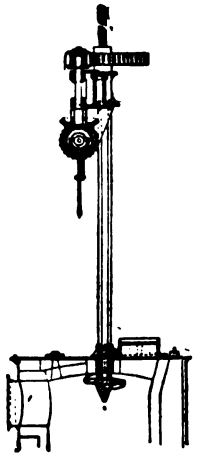


is intended to be worked by blast, there being two producers and two regenerator chambers working alternately, in order that the gas issuing from a producer should pass through one regenerator chamber and impart heat to it, which would in turn heat up the air for combustion on the currents being reversed by means of a valve.

In his latest modification, Mr. Sutherland introduces a stirring arrangement (Fig. 170) consisting of a vertical spindle passing down through the top of the producer carrying on its end a stirrer to plough up the fuel.

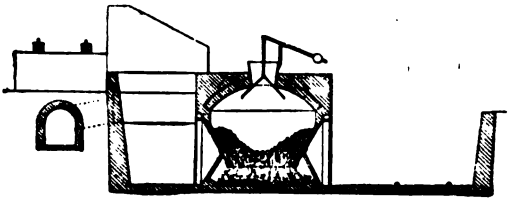
This is made preferably diamond-pointed, to enter and loosen the fuel, and carries two arms like propeller blades to screw their way into the fuel and loosen and break it up. This stirrer is driven by overhead gearing, and, according to Mr. Sutherland's account ("Jour. Iron and Steel Inst." 1884), materially reduces the labour of working the producers.

Fig. 170.



Siemens.—Numerous plans of gas producers have been proposed during the last five or six years which cannot be described, but one which merits notice is the circular producer introduced in 1881 by the late Sir William Siemens. This is practically the same form as was proposed by Mr. B. D. Healey (Fig. 171) in a paper on "The Manufacture of Steel" (read to the Institution of Engineers and Shipbuilders in Scotland on 23rd April 1872) with the addition, as first proposed by Siemens (Figs. 172, 173), of a blast-pipe first coiled in the gas collecting space at the top of the producer, and then either carried up and passed vertically down through the charging hopper to the centre of the mass of fuel, or first down through the brick lining and then up vertically. In both cases the bottom of the producer was open so that ashes should fall out on to a floor, and a tray providing water was placed so

Fig. 171.



that steam should be formed by the heat of the ashes. The difficulty of working such an open-bottomed producer with a pressure of blast, however,

Fig. 172.

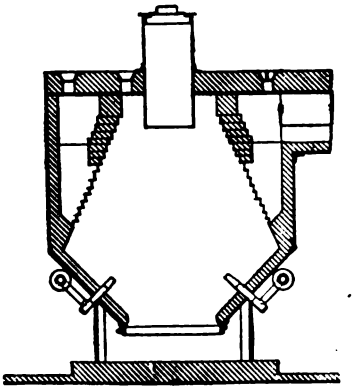
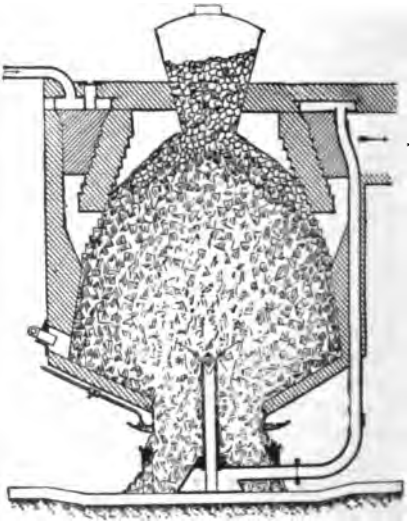


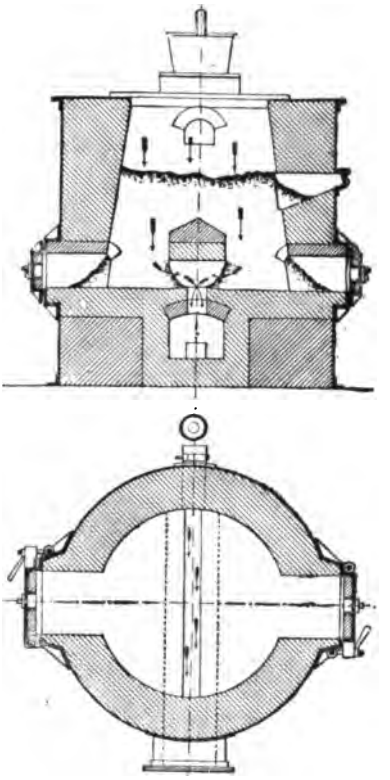
Fig. 173.



was apparent, and in several places where it was at first introduced this producer was worked by a chimney draught, a small steam-pipe being arranged to direct a spray of steam on the hot ashes as they issue from the opening at the producer bottom. Some steam was thus sucked in by the ingoing current of air.

Howson.—Mr. R. Howson of Middlesbrough has proposed a new modification of the closed hearth producer in which air is forced in by steam-jets above the surface of the charge of fuel, and the gases are led downwards through the fuel to openings made in the hearth which communicate with the gas flue. These openings may be made in a bridge running across the centre of the hearth, and may lead directly into a flue underneath, or they may be arranged to communicate with circular channels outside the combustion chamber and thence with a main flue below. Fig. 174 illustrates this producer. The introduction of the steam and air above the charge renders overheating of the charging hopper and bell cone impossible, and by preventing the escape of gas when poking holes are opened it facilitates the operation of poking or stirring the fuel. It is claimed that this producer is easily cleaned, the passing of the gases downwards having the effect of preventing the formation of clinker. Condensable hydrocarbons are also broken up by this process, and it is of course impossible to obtain either ammonia or tar from gases so treated.

Fig. 174.



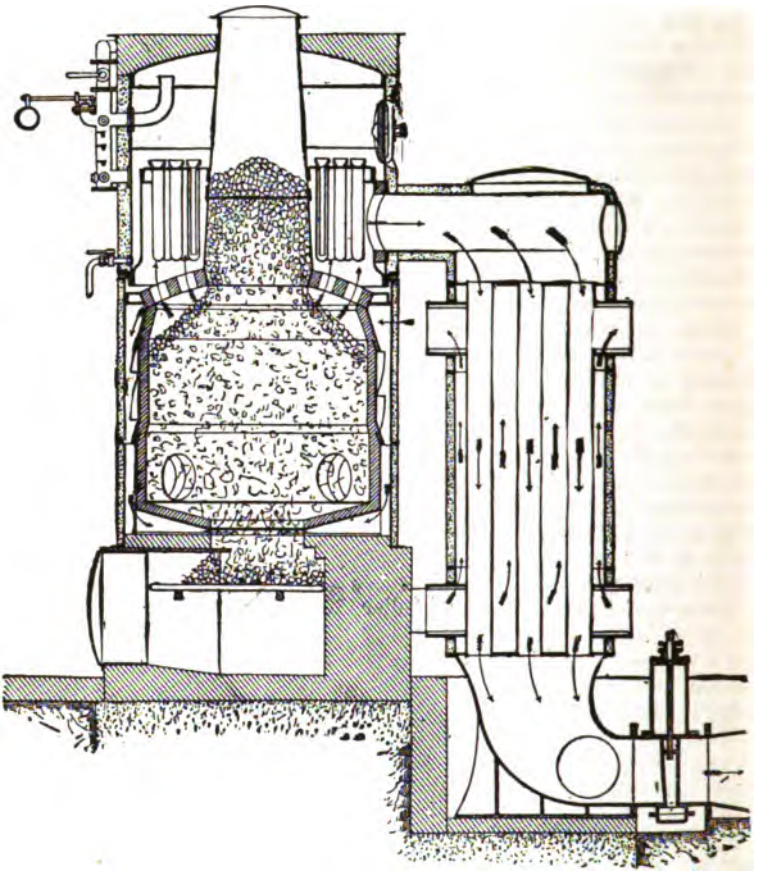
Müller and Fichet.—Messrs. Müller and Fichet have designed what they call a Universal Gas Producer. It is illustrated by Fig. 175, and consists, according to the inventors, of a cylindrical or rectangular body of boiler-plate or cast iron, furnished with a lining of refractory material. In this vessel the fuel is gasified. Air is forced in at the lower part by means of a steam-jet, and the slightly funnel-shaped base acts to direct the mixture of steam and air to the middle of the fuel. The top of the retort is formed by a fire-brick arch perforated by holes allowing the gas to pass to an upper chamber. Through the axis of this chamber passes a hopper of boiler-plate, resembling a truncated cone, attached to the roof of the retort and serving for the introduction of the fuel. The fuel descends slowly till it reaches the retort, where it is distilled by the heat of the gases passing through the perforated arched roof. The heat from this source also serves to generate the steam necessary for admitting the air. To this end, the upper chamber forms a steam boiler furnished with Field tubes distributed around the hopper which passes through it axially.

This arrangement utilizes the greater part of the heat of the gases of combustion without any admixture of air. In order to cool the gases completely before distribution, they are, on their exit, made to traverse in

a downward direction a nest of tubes around which circulates the mixture of steam and air furnished to the retort by the injector. By this means the air is heated without expense.

In order to avoid loss of heat by radiation, the generator is furnished with a double envelope, the outer wall of which is further covered with a layer of non-conducting material. In the annular space thus provided, the air to feed the furnace circulates after passing round the tubes in the gas cooler. By this means the mixture of air and steam attains a high temperature before coming in contact with the fuel, and thus allows a higher proportion of steam to be used than would be possible without superheating.

FIG. 175.

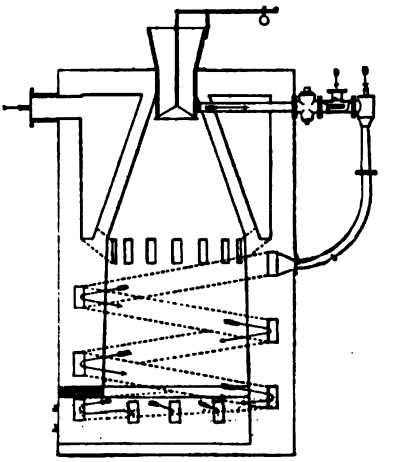


The steam is decomposed in its passage through the generator, and is converted into combustible gas. It might be said, therefore, that the sensible heat of the gas is utilized at the time of its production in order to augment its calorific power. The cooled gas can be distributed to the various furnaces of a factory to be there burnt in the ordinary way with cold or hot blast, and, on occasion, can itself be heated by passing through regenerators according to the heat desired to be attained in the furnaces. This generator has been arranged so as to utilize inferior coal. Instead of attempting, as some have done, to melt the ash, Messrs. Müller and Fichet have sought to obtain a moderate rate of working. A convenient number of openings at the

bottom of the generator allow of its being cleaned out. Generally, the burning fuel reposes on a bed of ash and scoria easily permeable by the air. When this bed becomes too thick it is cleared out, and in ordinary work it is sufficient to do this once a day. The joints are made with asbestos cloth, which prevents the escape of the gases. Below the tubular cooler is a casting of one, two, or three pipes, furnished with valves to direct the gases as desired. As regards the rate of working, this producer, the inventors say, can easily gasify 100 to 120 kilograms of fuel per square metre of section (20.5 to 24.6 lbs. per square foot) per hour, and by slightly augmenting the force of the blast employed the work can be increased. If coal of too rich a quality be employed, distillation will be produced in the hopper surmounting the retort, causing the accumulation of a mass of coke which will not feed properly into the vessel below. If such fuel were used, it would be necessary to have at the base of the arched roof several holes through which iron bars could be introduced to break up the coke.

Tervet.—Mr. R. Tervet has proposed* the form and arrangement of producer illustrated by Fig. 176. His object in this design was twofold, viz., to lessen the quantity of atmospheric air introduced into the producer for the production of carbonic oxide, and, while producing good heating gas, to combine with this the recovery of the greater part of the nitrogen of the coal as ammonia.

FIG. 176.



In describing this producer he remarks that it will be observed that the decomposition of the coal is divided into two stages. Supposing the producer to be at work and the upper cone to be full, as the total contents sink within the body of the producer there must remain a space between the mass of caked coal and the wall of the retort. The new charge passes into this space in a comparatively thin layer all round, where it undergoes incipient distillation yielding gas and tar. These in the form of vapour are drawn out from the retort by a steam-jet, and together with a regulated supply of air are passed several times round the body of the producer and finally into the culvert underneath, and thence through the incandescent coal, where the steam and tar are decomposed and the gases are conducted away in the ordinary manner. It is apparent, Mr. Tervet remarks, that an equilibrium of exhaust and pressure must be set up by the action of the steam-jet within the producer. Thus the upper cone or retort is always under exhaust while the lower portion or body of the producer is under pressure. The apparatus has worked admirably, destroying all the tar, yielding a very pure gas and recovering a large percentage of ammonia.

Thwaite.—Mr. B. H. Thwaite's designs, also communicated to Min. Proc. Inst. C.E. vol. lxxxiv. pp. 104, 105, are shown in Figs. 177, 178. His "twin" gas producer is founded on the general principles, that the volatile hydrocarbons from bituminous or semi-bituminous coal must be made to traverse the incandescent carbon in order to decompose the tarry matters, that the method of construction should render it impossible for air-currents to pass up the inside walls and dilute the combustible gas, and

* See "Min. Proc. Inst. C.E.," vol. lxxxiv. p. 101.

that the walls or sides of the producer internally should be smooth, so as not to afford any projections upon which clinker can hang and form scaffolds. These requirements he carries out in his "twin" producer by having the outlet for the gas at the level of the incandescent fuel, and arranging it in the centre of the producer with a fuel shaft and hopper on either side. He uses grate bars in this producer, and delivers air and steam from a steam-jet blower below them.

For clinkering, he uses false or clinkering bars, driving them in across the producer above the permanent fire-bars; the latter can then be withdrawn, when the clinker falls down

Fig. 177.

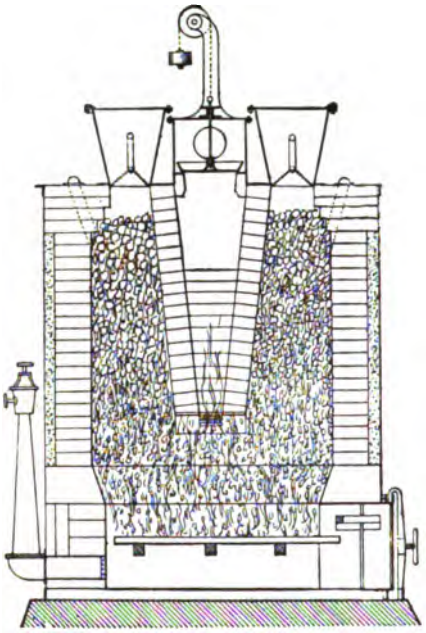
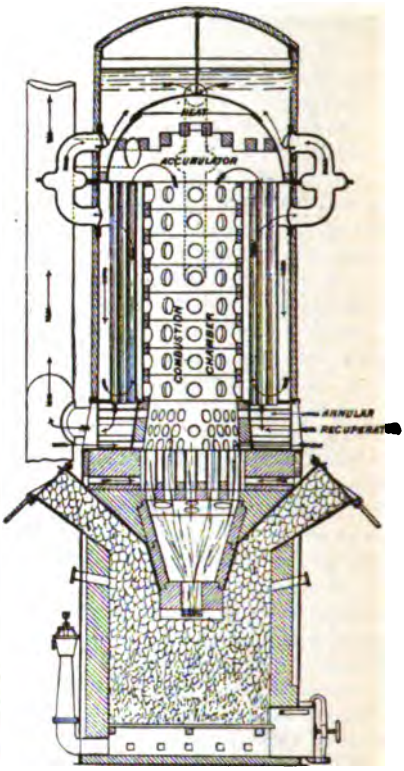


Fig. 178.



into the ash-pit. The fire-bars are then restored and the clinkering bars removed.

Mr. Thwaite does not say whether this producer has been worked, or whether he deduces its qualities from its design.

It appears to be probable that in working it the greater part of the combustion will be found to take place between the fire-bars and the outlet for the gas, and that in the coal shafts (having only one side exposed to the heat transmitted from the escaping gas while their other surfaces are exposed to cooling action) very little distillation of the fuel can take place; consequently only a very small portion of the hydrocarbons can traverse any incandescent carbon. The central outlet will prevent air currents as desired, but no better than the plan of delivering the blast at the centre of the fuel.

As regards the general principle of decomposing the tars by causing them to traverse incandescent carbon, it is not proved that this is necessary. It would appear to be sufficient if they are exposed to a sufficiently high temperature, either by radiation from the incandescent fuel or by contact with the hot gases from the fuel. Contact with the hot brick lining of

the producer would also do quite well, so that too much may be made of having the outlet for the gases in the centre of the incandescent fuel. In Tervet's producer, the hydrocarbons are made to do another duty in contact with the incandescent coke, viz., to supply the proper atmosphere for the preservation of the nascent nitrogen or newly formed ammonia from the coal.

In Fig. 178, we have Mr. Thwaite's producer as "adapted" for (we are not told whether it has been applied to) firing the Thwaite steam generator. In this arrangement of the producer, the depth of fuel from the gas outlet to the fire-bars is much greater than in Fig. 177, whilst the coal shoots have become mere hoppers. It is, however, probable that this producer as thus arranged will give better results than as shown in Fig. 177.

Several plans have been proposed for producing combustible gas by processes involving other reactions besides those of the combustion of fuel in air. Among these are J. F. Parker's process* for the use of a mixture of liquid hydrocarbons with either calcic carbonate or calcic hydrate, which he heats in retorts; a similar process of Sydney Pitt's;† the numerous plans for making oil-gas;‡ and in a manner akin to these are several proposed processes for the manufacture of oxygen on a commercial scale. (See "Jour. Soc. Chem. Industry," Feb. 1882 and Aug. 1882; "Engineering," Oct. 15, 1869, p. 255, Aug. 12, 1870, p. 117; W. Noel Hartley, "Air in its relation to Life," &c., pp. 37, 38.)

RECOVERY OF AMMONIA AND TAR FROM COAL AND GASES.

Young and Beilby.—Although the apparatus patented by Messrs. Young and Beilby was devised primarily to recover the nitrogen in shale and coal as ammonia, yet as part of it is applicable to the production of heating gas, and as even in the process of recovering the ammonia from coal some heating gas of a certain quality is produced, this notice of the various methods of producing fuel gas would not be complete without some reference to these plans as connected with them.

In working the apparatus for the distillation of shale for the production of oil, paraffin, and ammonia, a certain quantity of gas is made from the shale, which is used to heat the shale retorts along with an additional quantity derived from the treatment of coal in a vertical shaft or producer, which is combined with each group of eight shale retorts (see Figs. 179 and 180). This coal-shaft is built of brickwork, and is heated externally by the combustion of some of the gas with air heated by waste heat. This combustion takes place in the lower portion, and the heated products of combustion circulate partly in passages surrounding the shaft and extending nearly to its top. At the top is a charging door and cover, and just below is the exit pipe for the gases from the coal. The coal rests on grate bars, below which there is an ash pit. In the upper portion of the shaft, the coal is distilled partly by the externally applied heat and partly by the heat carried up by the hot gases from the combustion in the lower portion. The coke or fixed carbon is consumed by means of air admitted through the grate, combined with a large volume of steam, which is injected into the burning fuel at a short distance above the fire bars. The object of the admission of steam in large volume is to secure and preserve the nitrogen of the coal as ammonia, for which purpose a moderate temperature must be maintained in the region of combustion; as a further precaution against producing a temperature which would destroy the ammonia, a quantity of the gas which has passed through the condensers and scrubbers is returned into the producer.

* 1880 and 1881. † No. 2544—1883.

‡ For an account of some of these see "Jour. Soc. Chem. Ind.," 1884, p. 462; 1882, p. 314.

In apparatus erected by Mr. Beilby, at Oakbank Oil Works, for the treatment of coal exclusively, a number of vertical retorts are grouped together (see Fig. 180) in a "bench" or double row, with passages surrounding them for circulation of the heating gases. These are also built of brick, but differ from the coal shaft in Fig. 179 by having the exit pipe for the gases at about the middle of their height. The coal is fed in from hoppers at the top, and is distilled at a good heat in the upper half of the retorts. The tar vapours, together with steam, pass down through hot coke, and are decomposed into permanent gases and ammonia, no tar being found in the pipes when the temperature is properly regulated. The coke passing down into the lower half of the retorts is burned in a mixture of steam and air, with excess of steam, in order to secure the ammonia; and the gases from this portion ascend and pass away by the exit pipe. In starting these retorts, it is necessary to obtain some gas for combustion in the chambers surrounding them in order to heat them up. This may be made from coke in the subsidiary producer (K) placed alongside. The gases from the retorts

Fig. 179.

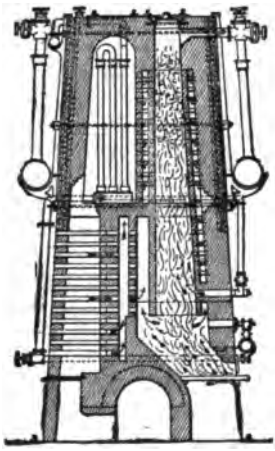
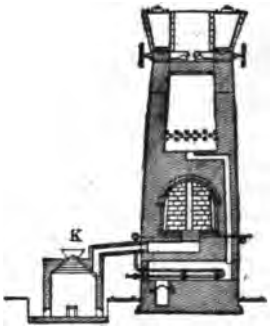


Fig. 180.



are drawn away by the main and are passed through condensers and scrubbers where the ammonia is separated and recovered, as much as from 90 lbs. to 125 lbs. of sulphate of ammonia per ton having been obtained from coal containing nitrogen equal to 165 lbs. to 170 lbs. of sulphate of ammonia per ton.

The gases from gas producers, as well as those from blast furnaces and coke ovens, have had attention turned to them as sources of ammonia, and although results as good as those obtained from the Young and Beilby plant are not to be expected where the primary object is the production of good heating gas, yet from 20 lbs. to 25 lbs. of sulphate of ammonia per ton of coal consumed may be recovered.

The only plans hitherto proposed for application to the gas from producers are the ordinary gas works plant, as applied by Messrs. W. Baird and Co. to blast furnace gases at Gartsherrie, and advocated for application to producer gas by Mr. W. S. Sutherland, and the system applied by Messrs. R. Addie and Sons, to blast furnace gases at Langloan Works, Coatbridge, and advocated for application to producer gas by Mr. Alfred Wilson and Mr. F. J. Rowan.

As has been already remarked, the Messrs. Neilson work a slightly different process at Summerlee Iron Works, applied to blast furnace gases, but not as yet to gas producers. In general, the recovery of ammonia and tar from

the gases from coke ovens is carried out on the plan of condensation and washing with water as in ordinary gas works, but if we except the Jameson coking process, in which air is admitted to the interior of the ovens, there is a strict similarity between the quantities and nature of the products treated in these operations—the quantity of gas being, however, rather less from close coke ovens than from gas retorts.

In the case of blast furnaces and gas producers, the conditions are, however, very different. In these, one ton of coal yields 130,000 cubic feet of gas, or more, according to the temperature of the gas, weighing nearly 4 tons, and having a temperature of not less than 500° F. This large quantity of gas does not contain on an average more than 7½ lbs. of ammonia (equal to 30 lbs. of sulphate of ammonia), and the difficulty of recovering this quantity may be estimated from the fact that the 10,000 to 12,000 cubic feet of gas from gas works retorts or the 8,000 cubic feet from close coke ovens, are treated for the same quantity of ammonia. In dealing with the gases of blast furnaces and gas producers worked with air and steam, we have thus to cool and manipulate more than 13 times that volume of gases, with the further disadvantage that the tar from these gases is of comparatively little value. It is therefore obvious, that in order to cool the gases from one ton of coal from blast furnaces or gas producers, thirteen times the cooling power is required as compared with what is required to cool the products from one ton treated for making lighting gas, and this additional outlay for plant is not even recompensed by the same return in products recovered. Despite the enormous demands of this method in size and cost of plant, it has been successfully adopted at Gartsherrie under the patents of Messrs. Alexander and McCosh, and similar arrangements are proposed by Mr. Sutherland in the Journal of the Iron and Steel Institute, vol. i. 1884, Plates III. to VII.

The process of Messrs. Addie does not involve the cooling of the enormous volume of gases to anything near the same point, and the plant required is much more moderate in dimensions. The process consists in treating the furnace gases with sulphurous acid in the state of gas, mixing it with the furnace gases at any convenient point. The result is the instantaneous formation of sulphite of ammonia in the gaseous form, which is readily separated by scrubbing with water in vertical scrubbers, in which the

FIG. 181.

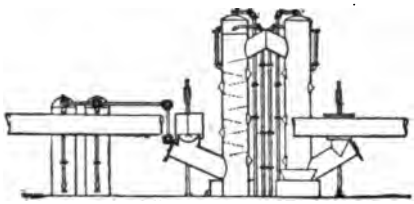
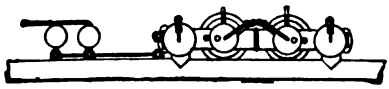


FIG. 182.



water is kept in circulation by pumping. The arrangement of plant is illustrated in Figs. 181, 182,* but when applied to blast furnace gases there are no pipes provided for externally cooling the scrubbing towers. These were introduced into this design by Mr. A. Wilson, in view of the higher tempera-

* Figs. 143 to 182 inclusive are reproduced from "Min. Proc. Inst. C.E.," vol. lxxxiv. by kind permission of the Council of the Institution.

ture of gases from gas producers, in order to prevent the carrying over of steam with the gases which have subsequently to be burnt for producing heat. Mr. Wilson remarks ("Jour. Soc. Chem. Ind.," 1883, p. 453) that in the case of the treatment of gases not exceeding 500° F., every drop of water used is used inside the scrubbers, and comes out as strong liquor. The water pumped in at the top of the scrubbers rapidly rises in specific gravity to any desired strength, even up to 40° or 50° Twaddell, if necessary, by the solution of salts of ammonia. This liquor is then converted into sulphate by distillation with lime in the ordinary way, but may be employed as it stands for many purposes, such as the production of ammonia for the ammonia-soda process or for the manufacture of liquor ammonia. The following analysis from Mr. R. R. Tatlock, represents the conditions of combination in which the ammonia existed in a sample of the crude liquor of 15° Twaddell:—

	Per Cent. Weight in Volume.		
Sulphate of ammonia	2.57	containing ammonia	.66
Sulphite „	3.44	„ „	1.01
Hyposulphite „	4.18	„ „	.96
Total ammonia salts	10.19	„ „	2.63
Specific gravity	1.076		

The sulphurous acid is obtained from sulphurous shale, coal brasses, or any kind of waste sulphurous materials, but it may also be produced from pyrites. These materials are burnt in a suitable retort by means of a forced current of air, and the sulphurous acid gas is conveyed by a pipe to the mixing point in the gas main.

To show that the whole of the sulphur thus introduced into the gases is arrested in the scrubbing plant, the gas at Messrs. Addie's from the flue beyond the scrubbers was tested for sulphur by Dr. Clark, with the following result:—

Sulphur per cubic foot of gas	0.1 grain
„ „ ton of coal burned	1.85 lb.
„ „ cent. of coal burned	0.08

"From this it will be observed," remarks Mr. Wilson, "that the sulphur in excess is only a mere fraction—probably not more than one-tenth—of the amount which must exist originally in the coal itself," so that for metallurgical purposes the quality of the gas as regards the sulphur from the coal is improved by this process.*

Composition of Gas from Producers.—The gases from generators, being prepared with a special view to their application as fuel, do not vary so much in composition as those from furnaces which can only be withdrawn so as not to interfere with the smelting process.

The following is the composition of producer gases:

PRODUCER GASES FROM WOOD CHARCOAL.

	I.	II.	III.	Mean Composition: By Volume.	Mean Composition: By Weight.
Nitrogen	63.37	62.38	64.47	63.41	64.9
Carbonic acid	0.45	0.59	0.50	0.51	0.8
Carbonic oxide	33.63	32.74	33.51	33.29	34.1
Hydrogen	2.55	4.29	1.52	2.79	0.2
	100.00	100.00	100.00	100.00	100.0

* For a full account of the various plans for the recovery of ammonia and tar from blast furnace gases, see W. Jones in "Jour. Iron and Steel Inst.," vol. ii. 1885, pp. 410–447.

PRODUCER GASES FROM WOOD.

FIRST KIND.

	I.	II.	III.	Mean Composition of II. & III.:	
				By Volume.	By Weight.
Nitrogen	51.54	50.72	49.48	50.11	53.2
Carbonic acid	9.55	6.67	7.80	7.23	11.6
Carbonic oxide	29.45	32.21	32.59	32.40	34.5
Hydrogen	9.46	10.39	10.13	10.26	0.7
	100.00	100.00	100.00	100.00	100.0

SECOND KIND.

	I.	II.	III.	Mean Composition:	
				By Volume.	By Weight.
Nitrogen	51.34	49.14	49.64	49.97	55.5
Carbonic acid	12.70	13.43	13.27	13.20	22.0
Carbonic oxide	18.86	18.60	19.48	18.98	21.2
Hydrogen	17.10	18.83	17.61	17 85	1.3
	100.00	100.00	100.00	100.00	100.0

PRODUCER GASES FROM TURF OR PEAT.

	I.	II.	Mean Composition:	
			By Volume.	By Weight.
Nitrogen	64.13	58.8	61.47	63.1
Carbonic acid	7.32	10.79	9.06	14.0
Carbonic oxide	22.63	21.04	21.83	22.4
Hydrogen	5.92	9.36	7.64	0.5
	100.00	100.00	100.00	100.0

PRODUCER GASES FROM COKE.

	I.	II.	Mean Composition:	
			By Volume.	By Weight.
Nitrogen	64.64	63.63	64.14	64.8
Carbonic acid	0.80	0.91	0.85	1.3
Carbonic oxide	33.31	33.76	33.53	33.8
Hydrogen	1.25	1.70	1.48	0.1
	100.00	100.00	100.00	100.0

The apparent absence of all hydrocarbons in these mixtures of gases, is due to the method of analysis adopted by Ebelmen; these ingredients would probably only enter in small proportion into the mixture, and the numbers given above may therefore be employed for all practical purposes in calculating the relative heating values of the gases.

Although in recent years the use of gas producers in connection with many heating operations has very largely increased, there are as yet comparatively few published analyses of the gases so produced.* In particular there are very few available analyses of gas from the Siemens producer, and

* See the Table of Analyses in "Min. Proc. Inst. C.E.," vol. lxxxiv. pp. 50, 51.

consequently, in treating of this subject, reference is made frequently to the following analysis made at St. Gobain, and published some years ago :*—

ANALYSIS OF GAS FROM SIEMENS PRODUCERS.

	Per Cent. by Volume.	
Carbonic oxide	24.2	combustible
Hydrogen	8.2	
Hydrocarbides	2.2	34.6
Carbonic acid	4.2	incombustible
Nitrogen	61.2	65.4
	100.0	

This analysis was published by Kraus in 1865 (or 1869),† and represents the mean quality of gas obtained from the producers at the Plate Glass Works, St. Gobain, France, burning a mixture of ¾ caking coal and ¼ non-caking coal.

M. Boistel, in a communication to the *Société des Ingénieurs Civils*, dated August 1867, gave the following average composition of Siemens producer gas :—

Carbonic oxide	21.5 to 24.	per cent. by volume
Carbonic acid	4. „ 6.	„ „
Nitrogen	60. „ 64.	„ „
Hydrogen	5.2 „ 9.5	„ „
Hydrocarbons	1.3 „ 2.6	„ „
	100	

Referring to the St. Gobain analysis, Mr. C. W. Siemens made‡ the following remarks regarding the action of his cooling-tube. "The gas rising from the producer at a temperature of about 1100° F. is cooled as it passes along the overhead tube, and the descending column is consequently denser and heavier than the ascending column of the same length, and continually overbalances it. The system forms in fact a syphon in which the two limbs are of equal length, but the one is filled with a heavier fluid than the other. The height of cooling tube required to produce as great a pressure in the flue as would be obtained by placing the gas producers, say, ten feet deeper in the ground, may be readily calculated. The temperature of the gas as it rises from the producers has been taken as 1100° F., and we may assume that it is cooled in the overhead tube to 100° F., an extent of cooling very easily attained. The calculated sp. gr. referred to hydrogen, of the gas of which I have quoted the analysis being 13.14, we obtain the following data :—

	lb.
Weight of the gas per cube foot at 1100° F.	= .022
„ „ „ 100° F.	= .061
atmospheric air per cube foot at 60° F.	= .076

and from these we have, on the one hand, the increase of pressure per foot of height, in a flue rising directly from the gas producer,

$$= .076 - .022 = .054 \text{ lb. per square foot;}$$

and on the other hand, the excess of pressure at the foot of the downtake from the cooling tube over that at the same level in the flue, leading up from the gas producer (for each foot in height of the cooling tube),

$$= .061 - .022 = .039 \text{ lb. per square foot.}$$

The height of the cooling tube above the level of the flue that will be

* See "Jour. Chem. Soc.," 1868, p. 279. Siemens on the Regenerative Gas Furnace.
† See *Mémoires de la Société des Ingén. Civils*, No. 28, 1874, p. 782. ‡ *Op. cit. ante.*

sufficient to produce the required pressure, equal to 10 feet of heated gas column, is therefore,

$$\frac{.054}{.039} \text{ 10 feet} = 13' \text{ 10}'', \text{ or say 14 feet.}"$$

M. Sylvain Périssé, in a paper in the *Mémoires de la Société des Ingénieurs Civils* (No. 28, Oct. to Dec. 1874, pp. 752, 812) on the Ponsard furnace has given the following analyses of gas as generated in Ponsard producers which are of the Siemens form with some slight modifications :—

	I.	II.	III.	IV.	V.	
Carbonic oxide . . .	21.0	25.0	22.5	22.0	24.0	
Carbonic acid	6.0	4.0	4.5	4.4	4.0	
Nitrogen	61.0	60.0	57.0	52.0	55.0	By calculation.
Hydrogen and hydrocarbons .	12.0	11.0	16.0	21.6	17.0	By difference.
Volumes . .	100.0	100.0	100.0	100.0	100.0	

I. The coal used was a caking coal, which on analysis, after drying at 110° C. (230° F.) gave 79 to 81 per cent. of coke, and 21 to 19 per cent. of volatile matter. The quantity of ash varied from 9 to 18 per cent. Cinders amounting to about $\frac{1}{5}$ of the quantity were charged with the coal. Cold air was used, but the producer was worked fast.

II. The producers were charged with $\frac{3}{5}$ of good coal and $\frac{2}{5}$ cinders from other fires. Ordinary producer with cold air. Temperature of gas about 650° C.

III. Producer worked with forge coal giving 73 per cent. coke, well formed but feebly swelled, and 27 per cent. volatile matter.

The coal contained 20 per cent. ash, and was used without admixture with cinders. The gas escaped from the ordinary producer at 850° C. Water was allowed to trickle under the grate from a tap.

IV. Hot air from the Ponsard recuperator was supplied to the producer, but the air was not freed from moisture. The coal was a gas coal giving 65 per cent. of a feebly formed coke, and 35 per cent. volatile products. Ash 15 to 20 per cent.

Temperature of the gas equal to that of melting copper.

V. Same conditions as No. IV., but with the air dried.

ANALYSES OF GAS PRODUCED FROM PEAT.

	Ponsard Producer. VI.	VII.
Carbonic oxide	21. ...	23.
Carbonic acid	11. ...	9.

No. VI. Peat very wet, containing 50 per cent. water, but there was a slight loss of water, while it was kept in the boxes before charging.

VII. Wet peat, containing 28 per cent. water. The peat used in VI. and VII. gave after desiccation :—

Volatile matter	58.5 per cent.
Solid (including ash) . . .	41.5 ,,

Ash amounted to 8 per cent.

ANALYSES OF GAS PRODUCED FROM COKE AND WOOD CHARCOAL.

	From Siemens' Producers with Coke.	Ebelmen's with Dried Air.	With Wood Charcoal with Moist Air.
Carbonic oxide	26.0	33.3	27.2
Carbonic acid	4.5	0.5	5.5
Nitrogen	67.5	63.4	53.3
Oxygen	0.5	—	—
Hydrogen	not given.	2.8	14.0
	—	100.0	100.0

The first of these analyses is from the work of M. Felix Leblanc, on the Gas Works of the *Compagnie Parisienne.*

ANALYSES OF GAS FROM WILSON PRODUCERS.

	I.	II.	III.
Carbonic oxide	26.89	23.41	23.60
Marsh gas (CH_4)	1.45	2.22	3.05
Hydrogen	11.55	13.82	10.55
Nitrogen	56.11	55.86	57.55
Carbonic acid	4.00	4.69	5.25
Volumes	100.00	100.00	100.00
Total percentage of combustibles	39.9	39.45	37.2

No. I. Analysed by Pattinson and Stead, of Middlesbro', from producer using Durham coal.

No. II. Analysed by Pattinson and Stead, being average of 6 samples taken during an hour from a producer working on fine Yorkshire slack.

No. III. Analysis by the Director of the Hainault Glass Works, Roux, near Charleroi. Producer using Belgian coal.

The following analyses of gas from Wilson producers were made by the engineer to the Plas Power Colliery, Wrexham, in connection with some comparative tests of gas firing as against hand firing for the steam boilers of the colliery:—

Description of coal used, IV. refuse, V. and VI. best coal.

ANALYSIS OF GAS.

	IV.	V.	VI.
Carbonic acid	7.14	4.11	6.26
Oxygen	0.00	0.00	0.00
Hydrogen	12.15	12.42	14.68
Carbonic oxid	19.83	26.48	23.98
Marsh gas	3.61	5.91	4.72
Nitrogen	57.24	51.06	50.36
	99.97	99.98	100.00

IV. Pressure of gas in producer, 20 millimetres.
Temperature of gas in producer, 960° C.
" " above gas valve at boiler, 740° C.
" " fuel of producer, 1300° C.
V. and VI. Pressure of gas in producer, about 22 millim.
Temperature of gas in producer, 600° C.
" " at gas valve at boiler, 450° C.
In these latter trials, the column of fuel in the producer was kept 2 feet

higher than in No. IV., and a larger amount of steam was allowed to enter the producer by the steam jet, at a lower velocity than in No. IV.

The following analyses of producer gas were published by the late Mr. Magnus Troilius, chemist to the Midvale Steel Co., Philadelphia : *—

Notes.	Philips Producer at Hoopes and Townsend.						Siemens Producer Midvale.		
1a and 1b from different producers, but at the same time. 2a and 2b, ditto. 3a and 3b from the same producer. The last two analyses from Midvale belong together, being taken with half an hour interval.	No. 1a Fan Blast. Hot Working Producer.	No. 1b Steam Blast. Cold Working Producer.	No. 2a Steam Blast. Just before cleaning Producer. Bad Coal.	No. 2b Steam Blast. Bad Coal.	No. 3a Steam Blast. Normal Running.	No. 3b taken 10 Minutes after 3a with Air shut off as far as possible, and only Steam let on.	Samples taken just after cooling down Fires with Water from below.	Sample taken just before cooling Fires with Water.	Samples taken just after cooling down Fires with Water from below.
Carbonic acid, CO_2	3.9	8.7	9.3	7.5	8.0	6.1	5.7	1.5	5.9
Ethylene, C_2H_4	—	—	—	—	—	—	.9	—	—
Carbonic oxide, CO	27.3	20.0	16 5	16.0	15.5	22.3	15.4	23.6	17.7
Hydrogen, H	—	8.7	8.6	15.3	14.9	28.7	8.3	6.0	9.8
Marsh gas, CH_4	1.4	1.2	2.7	1.9	—	1.0	3.8	3.0	2 4
Nitrogen (difference), N	67.4	61.4	62.9	59.3	61.6	41.9	65.9	65.9	64.2
Totals	100.0	100.0	100.0	100.0	100.0	100.0	100.0	100.0	100.0
Calories per 100 litres at 0° and 760 mm.	93.966	97.184	99.074	111,474	92.620	164,164	116 753	114,939	103,843
Flame temperature	1,619°	1,658°	1,575°	1,706°	1,613°	1,846	1,656°	1,761°	1,642°

The following comparative table of properties and composition of various kinds of gaseous fuel is from a paper by Mr. Alfred Wilson ("Proc. Cleveland Inst. of Engineers," June 9, 1879) :—

No.	Gases.	Composition of 100 Parts by Weight.						Percentage of Combustible.	lbs. of Air to Burn 1 lb.	Centigrade lb. Units Produced. Combustion under Constant Pressure.	Theoretical Maximum Temperature. Deg. Cent.
		N.	H.	CO_2.	CO.	CH_4.	C_2H_4.				
1.	Blast furnace. Scotch	48.2	0.9	21. 7	29.24	—	—	30.14	0.96	946	2,010
2.	Blast furnace. Askam	52.59	0.14	13.47	33.80	—	—	33.94	0.9	859	1,873
3.	Blast furnace. Cleveland	58.54	0.06	14.32	27.03	—	—	27.09	0.87	669	1,917
4.	Producer gas. Siemens	64.5	—	6.95	24.92	0.89	2.73	28.54	1.17	1,038	2,000
5.	Producer gas. Siemens	63.22	0.65	8.71	25.97	1.45	—	28.07	1.11	1,036	2,055
6.	Producer gas. Wilson	61.7	0.90	6.91	29.58	0.91	—	31.39	1.20	1,139	2,128
7.	Producer gas. Wilson	62.84	1.11	8.29	26.33	1.43	—	28.87	1.28	1,201	2,204
8.	Retort made town gas	—	8.17	—	13.61	56.10	17.12	100.00	15.60	12,623	3,171

NOTES.—No. 1 is from Sir I. Lowthian Bell's "Chemical Phenom. of Iron Smelting," p. 313; No. 2 is an analysis by W. Crossley; Nos. 3, 6, and 7 are by J. E. Stead, of Middlesbro'; Nos. 4 and 5 are by G. J. Snelus.

From a paper published by him in the Journal of the Society of Chemical Industry,† the following average analysis of gas from Mr. Sutherland's producer is given by the inventor himself :—

Carbonic oxide	34 to 30	per cent.
Carbonic acid	.2 „ 2.5	„
Nitrogen	55 „ 60	„
Hydrogen	4 „ 8	„

Mr. G. Beilby‡ gives the following as the composition of the gas from the Young and Beilby apparatus for the treatment of coal in order to obtain all the nitrogen as ammonia. He remarks "the dross used in these retorts contains nitrogen equal to 165 to 170 lbs. of sulphate of ammonia per ton.

* "Trans. American Inst. Mining Eng.," Feb. 1883.
† Feb. 1883. ‡ "Jour. Soc. Chem. Ind.," 1884, p. 216.

Results have been regularly obtained, yielding from 90 lbs. to 125 lbs. of sulphate per ton, or say 60 to 70 per cent. of the total nitrogen. The quantity of steam used has varied from 2500 lbs. to 3500 lbs. per ton of dross, equal to 250 to 350 gallons of vaporised water, so that the proportions of coal to steam now stand, 1 coal to 1¼ steam. The composition of the incondensable gas varies somewhat according to temperature, air supply, &c. A sample showed the following percentage composition, by volume:—

Carbonic acid	16.6
Carbonic oxide	8.1
Marsh gas (CH_4)	2.3
Hydrogen	28.6
Nitrogen	44.4
	100.0

With regard to this analysis, Mr. Beilby remarks that it indicates a rather excessive air supply, as the point aimed at in using this apparatus is to obtain a consumption of one-half of the fixed carbon with air and the other half with steam. Corrected to the results produced with such an admission of air, the composition of the gas would be:—

Carbonic acid	21.32
Carbonic oxide	10.72
Marsh gas, &c.	nil
Hydrogen	37.19
Nitrogen	30.77
	100.00

Elsewhere* Mr. Beilby has explained that in decomposing steam by incandescent carbon according to the equation

$$C + H_2O = CO + H_2 \qquad (I.)$$

the nitrogen contained in the mineral would not be recovered as ammonia, in consequence of the high temperature at which that reaction takes place. In his apparatus, a much lower temperature is maintained, and an excess of steam or other neutral gas (or of hydrogen according to Mr. Tervet's method) is used, the result of such lowering of the temperature being the formation of carbonic acid, thus:—

$$3C + 9H_2O = CO + 2CO_2 + 5H_2 + 4H_2O \text{ (excess)} \qquad (II.)$$

At the same time, the conditions are realized for the formation and preservation of ammonia from the nitrogen of the fuel, and as this is the main object of the Young and Beilby plans it is perhaps scarcely fair to class their apparatus with others whose object is the production of heating gas.

The reactions expressed by the preceding equations, excepting the excess of H_2O in (II.) show what takes place in the formation of so-called "water gas," that is, the gas resulting from the decomposition of steam by red-hot carbon. According to the temperature employed in the process, the mixture of gases contains more or less carbonic acid, but the first equation is of course what is aimed at by those who wish to make water gas for use as fuel. In practice, however, it has very seldom been attained, although of late years there have been some approximations to it.

Dr. Percy ("Metallurgy," vol. Fuel, p. 418) gives the following analyses of water gas made in the apparatus patented by Mr. J. Dawes, who he believes (p. 516) was the first to apply the mixture of gases so obtained:—

* "Proc. Inst. C.E.," vol. lxxvii. pt. iii.

COMPOSITION PER CENT. BY VOLUME OF GASES RESULTING FROM THE ACTION OF STEAM ON RED-HOT COKE.

	I.		II.
Hydrogen	54.52	...	56.90
Marsh gas	1.62		
Carbonic oxid	31.86	...	29.30
Carbonic acid	1.200	...	13.80
	100.00	...	100.00

The first analysis was made by Langlois, whose investigations of the subject of the action of steam on heated charcoal are also quoted by Dr. Percy (pp. 364, 365). These investigations showed that the gas obtained when the charcoal was red hot contained about 22 per cent. of carbonic oxide, and about 18 per cent. of carbonic acid, but that when the charcoal was kept at a *red-white* heat the proportion of carbonic oxide rose to 42 per cent. and that of carbonic acid fell to 6 per cent. The second analysis was made by Frankland.

The apparatus patented some years ago by Mr. Joshua Kidd, produced gas which, as analysed by Mr. T. W. Keates, consulting chemist to the Metropolitan Board of Works, gave the following results:—

Carbonic oxide	28.6 per cent.
Hydrogen	14.6 „
Nitrogen	53.0 „
Carbonic acid	4.0 „
	100.2

The nitrogen in this gas is of course due to the air which is forced into the fuel along with the steam.

The best quality of water gas obtained in practice seems to have been that produced by the Strong water gas apparatus, p. 261. The following is an analysis of the dry gas, after having been washed, made by Dr. G. E. Moore, of Jersey City, for the American Gas Fuel and Light Co., New York, who owned the patents for the Lowe and the Strong apparatus:—

"STRONG" GAS COMPOSITION BY VOLUME.

Oxygen	0.77 per cent.
Carbonic acid	2.05 „
Nitrogen	4.43 „
Carbonic oxide	35.88 „
Hydrogen	52.76 „
Marsh gas	4.11 „
	100.00

The weight of a cubic foot of this gas at 62° F. is stated to be 0.04116 lb and it requires for its combustion 2.47 cubic feet of air weighing 0.1880 lb. Dr. Moore states that the theoretical calorific intensity of the flame of this gas is over 5400° F., a temperature which of course could not be attained in practice, as it is beyond the point at which dissociation of the gases begins.

These facts seem to indicate that there is still room for a producer which will combine the action of the distilling retorts with the manufacture of water gas from the resulting coke, and which will thus utilize the whole of the fuel for the manufacture of gas, without deteriorating its products by any admixture of atmospheric air or nitrogen. Such a producer has been proposed by F. J. Rowan, in a British patent, No. 2693—1885.

NATURAL GAS AS FUEL.

In America, since the year 1875, considerable quantities of combustible gas have been obtained from wells or bore-holes, originally drilled in searching for petroleum. It may be stated, generally, that gas has been found in nearly every oil-well drilled; but all gas-wells do not yield petroleum. The use of this gas as fuel has grown to such importance that the area of territory containing gas-bearing strata is being carefully observed, and numerous bores have been drilled for gas, in order that it should be systematically used on an extended scale.

According to Mr. C. A. Ashburner,* a well at Sheffield, Pennsylvania, was drilled in 1875, and in September 1885 was still supplying that town with light and fuel. Mr. Andrew Carnegie† records that in 1878 a company drilled for oil at Murraysville, about eighteen miles from Pittsburg, and at a depth of 1,320 feet struck an enormous reservoir of gas, which escaped with such force that the drills and derrick were thrown high into the air, and broken, the roar of the escaping gas being heard in Munroville, five miles distant. The same writer observes that "it is now [1885] many years since the pumping engines at oil-wells were first run by gas, obtained in small quantities from many of the holes which failed to yield oil. In several cases, immense gas-wells were found near the oil-district; but some years elapsed before there occurred to any one the idea of piping it to the nearest manufacturing establishments, which were those about Pittsburg." One of the earliest attempts to use the gas for manufacturing operations seems to have been about 1879, when Mr. John Rogerson‡ states that he saw it used in puddling furnaces at an ironworks outside Pittsburg—the gas having been brought, he was told, a distance of about fifteen miles. This does not seem to be the same instance as is referred to by Mr. Carnegie when he says (speaking in 1885) that "some years ago the product of several gas-wells in the Butler region were piped to two mills at Sharpsburg, five miles from Pittsburg city, and there used as fuel, but not with such triumphant success as to attract much attention to the experiment. Failures of supply, faults in the tubing, and imperfect appliances for use at the mills combined to make the new fuel troublesome."

The Murraysville gas at first escaped from the well through four pipes, each of 2 inches diameter, ignited, and allowed to go to waste by burning uselessly for five years, although the well was only nine miles from the steel rail mills at Pittsburg; the reasons for this given by Mr. Carnegie being the cost of the pipe-lines, and also the fact that the business of conducting the gas to the mills, and of using it when it got there, was not understood until more recent times. Mr. Carnegie thus describes the appearance of the burning gas, as observed by him at Murraysville and at the wells in Washington County in the autumn of 1884:—"In the Murraysville district, the gas rushes with such velocity through a 6-inch pipe, extending, perhaps, 20 feet above the surface, that it does not ignite within 6 feet of the mouth of the pipe. Looking up into the clear blue sky, you see before you a dancing golden fiend, without visible connection with the earth, swayed by the wind into fantastic shapes, and whirling in every direction. As the gas from the well strikes the centre of the flame and passes partly through it, the lower part of the mass curls inward, giving rise to the most beautiful effects gathered into graceful folds at the bottom—a veritable pillar of fire. There is not a particle of smoke from it. The gas from the wells at Washington was allowed to escape through pipes which lay on the ground. Looking down from the roadside upon the first well we saw in the valley, there appeared

* "Trans. Amer. Inst. Min. Eng.," vol. xiv. pp. 428–439.
† "Jour. Iron and Steel Inst.," i. 1885, pp. 168–178. ‡ *Ibid.* p. 182.

to be an immense circus ring, the verdure having been burnt and the earth baked by the flame. The ring was quite round, as the wind had driven the flame in one direction after another; and the effect of the great golden flame lying prone upon the earth, swaying and swirling with the wind in every direction, was most startling."

In the early part of 1885, it was stated that eleven lines of pipe then conveyed gas from the various wells to the manufacturing establishments in and around Pittsburg, the largest of these pipes being, for the latter part of the distance, 12 inches in diameter. Some were of 8 inches throughout, while the lines originally laid were 6 inches in diameter. The cost of laying pipe-lines fell in 1885 to about £1,500 per mile, from about double that amount, which was the cost six to eight years previously, so that the cost of a line to Pittsburg might be said to be £27,000; the cost of drilling being about £1000. In 1883, a gas company offered to supply Messrs. Carnegie Brothers with gas for a sum per annum equal to their coal bill (their coal at that time cost three shillings a ton) until the capital outlay for piping was reached, when the gas was to be supplied at half the cost of the coal. It took eighteen months to recoup the gas company, and the success of the introduction of this fuel in this instance induced the starting of other pipe-lines for gas, and the leading of them into the city of Pittsburg, which is 15 to 18 miles from the wells. In a Paper read at the Pittsburg meeting of the American Institute of Mining Engineers, Mr. W. P. Shinn stated that, according to the report of one of the companies supplying the city of Pittsburg, the supply of gas was drawn from 42 wells, situated in the Murraysville, Tarentum, and Washington fields, about 20 to 22 miles from the Post Office. The mains and distribution pipes then laid were 1,773,662 feet, or 335 miles 4,862 feet, in length. The amount of coal displaced by this company's gas was about 10,000 tons per day. Mr. H. M. Chance* estimated that the total amount of coal displaced daily by gas about the end of 1885 was 10,000 to 15,000 tons; whilst Mr. C. A. Ashburner† states that, in the city of Pittsburg, 1,500 dwellings, 66 glass-works, 34 rolling-mills, and 45 other industrial establishments were in September 1885 being supplied with natural gas, mainly for heating purposes; the amount of coal displaced being estimated at 10,000 tons daily. The estimated value of the coal thus supplanted in Pennsylvania and the adjacent States, for three succeeding years, is given as follows:—

In 1882	£43,000
1883	95,000
1884	292,000

About two-thirds of the last amount (or £220,000) represents the consumption in the Pittsburg district.

The extent of the territory which may be considered either as the reservoir or as containing the source of natural gas has not yet been clearly defined. One writer states‡ that the district of natural gas covers a much greater area than that of oil. In general, it may be said to include a section of country extending from Western New York, through Pennsylvania into West Virginia and Ohio, and lying nearly parallel to the Alleghany Mountains. The width of this section varies considerably—the boundary lines are very irregular, and are being extended by the finding of new wells. Although the outlines enclose a large territory, gas is found in only a small portion of it, and then in spots and narrow belts or lines. It was estimated that in 1885 there were 500 gas-wells in the oil country and its vicinity, which were producing at least 100,000,000 cubic feet per day.

* "Iron Age," vol. xxxvii. No. 12. † "Trans. Amer. Inst. of Min. Eng.," Sept. 1885.
‡ "Iron Age," vol. xxxv. No. 17.

The principal gas-producing districts are evidently those of Murraysville and of Washington County. Dealing with the districts surrounding Pittsburg as a centre, Mr. Carnegie says* that in the Murraysville field he found, in the autumn of 1884, that nine wells had been sunk, and were yielding gas in large quantities. "One of these was estimated as yielding 30,000,000 cubic feet in twenty-four hours. This district lies to the north-east of Pittsburg, running southwards from it towards the Pennsylvania Railroad. Gas has been found upon a belt averaging about half a mile in width, for a distance of between four and five miles." Thirty successful wells are now in operation in this district. "Beyond that, we reach a point where salt water flows into the wells and drowns the gas. Several wells have been bored upon this belt near the Pennsylvania Railroad, and have been found to be useless from this cause. Geologists say that in this region a depression of 600 feet occurs in the strata, but how far the fault extends has not yet been ascertained. Wells will, no doubt, be sunk southwards of the Pennsylvania Railroad, upon this half-mile belt. Swinging round towards the south-west, and about twenty miles from the city, we reach the gas-fields of Washington County. There are now five wells yielding gas in that district, and others are being drilled. Passing still farther to the west we reach another gas territory, from which manufacturing works in Bever Falls and Rochester, some twenty-eight miles west of Pittsburg, receive their supply. Proceeding with the circle we are drawing in imagination around Pittsburg, we pass from the west to the north-west without finding gas in any considerable quantity, until we reach the Butler gas-field, equidistant from Pittsburg on the north-west with Washington Co. wells on the south-west. Proceeding now from the Butler field to the Alleghany river, we reach the Tarentum district, still about twenty miles from Pittsburg, which is supplying a considerable portion of the gas used. Drawing thus a circle around Pittsburg with a radius of fifteen to twenty miles, we find four distinct gas-producing districts. In the city of Pittsburg itself, several wells have been bored; but the fault before mentioned seems to extend towards the centre of the circle, as salt water has rushed in and rendered these wells wholly unproductive, although gas was found in all of them."

Since Mr. Carnegie recorded these observations, some very powerful gas wells have been found in Washington Co. It is said† that the most powerful gas-well in the world is to be found there now. The rush of gas was originally so great that it was almost beyond control, and there was a constant fear lest the tubing, &c., should be blown to pieces. It was consequently decided to sink another well within 100 feet of the first, in the hope that the gas-pressure would be thereby diminished. Instead of a 3-inch casing, the new well was lined with 6-inch heavy iron pipe, which was carefully secured. At the end of less than sixty days from starting the new bore, the depth of the first—called the McGuigan—well was reached, this depth being 2,238 feet, and scarcely any gas was found. At the depth of 2,250 feet, however, the gas was struck, tools were blown out, and then the greatest flow of gas observed as yet in the Washington field took place. An effect on the McGuigan well was immediately noticed; its roar diminished and its pressure became weaker, and it was finally screwed down; as a consequence of this operation, a larger quantity of gas issued from the new well.

Dealing with the geological formations in which natural gas is found, Mr. C. A. Ashburner‡ gives the results of observations made in connection with the geological survey of Pennsylvania. The oil and gas regions of

* "Jour. Iron and Steel Inst.," vol. ii. 1885.

† "Iron Age," vol. xxxvii. No. 10; "Jour. Iron and Steel Inst.," vol. i. 1886, p. 265.

‡ "Trans. Amer. Inst. Min. Eng.," Sept. 1885. See "Min. Proc. Inst. C.E.," vol. lxxxiii. p. 491.

Pennsylvania are substantially one in a geological sense. The strata drilled through by the gas wells in the vicinity of Pittsburg are in a general way the same as those of the Beaver and other oil districts, lying at distances varying from eight to forty-five miles from that place. Gas is a common associate of liquid oils, and the product of the so-called dry gas wells, though supposed to be free from oil and water, generally yields one or both in small quantity when subjected to great compression. The rocks of the oil and gas regions lie nearly horizontally in broad and almost imperceptible folds, whose axes are, roughly speaking, parallel to the escarpment of the Alleghany mountains. The maximum dip is 69 feet per mile, but is generally much less. The vertical range of gas-producing beds is included in about 3,000 feet of carboniferous and Devonian strata, extending from the Mahoning sandstone at the base of the lower barren coal measures, 500 feet below the Pittsburg coal seam, down to the Smithport oil sand. There are three principal gas horizons, the first being probably the representative of the Venango first oil sand, 1,800 to 1,850 feet below the Pittsburg coal; the second, the Sheffield gas sand, corresponding with the lowest oil bed of the Warren district, 2,220 feet below the Mahoning sandstone; and the third, the Bradford oil sand, 1,775 feet below the Pottsville conglomerate. In the adjoining States of West Virginia, Ohio, and Kentucky, natural gases have been obtained from lower horizons down to the lower Silurian limestones; but in the most productive wells the gas is derived from the Devonian sands. It is believed that the gas is not indigenous to the sand rocks producing it, but that it is derived from the decomposition of organic matter contained in the strata below. If this be so, the amount of gas contained in any one sand depends on the extent to which the rocks are cracked below it, to allow the gas from the lower fossiliferous level to flow upwards; and the continuity of the covering strata, which, if much cracked above the gas sand, would allow it to escape into the atmosphere and disappear. The absence of both petroleum and natural gas in the plicated strata east of the oil regions is evident from the fact that these strata extend far beyond the areas in which oil and gas are found, and even within these areas the direction of certain productive flows is due to the jointing of the strata.

Prof. E. Orton has examined the records and cores of six wells which were bored during 1884 in Hancock and Wood counties, Ohio. He reports* that they agree entirely in their main features. All begin in Upper Silurian limestone, and find their main supply of gas in the Trenton limestone. The Trenton limestone was drilled through in only one well. The gas obtained from these wells contained a notable quantity of sulphuretted hydrogen.

In selecting localities for boring gas wells, the so-called "anticlinal theory" has been most generally followed. This supposes that the most abundant flow will be obtained on or near the summit of an anticlinal arch; but this is not of universal application, because in many notable instances the gas has been found in synclinal troughs or in perfectly horizontal strata. On the other hand, some of the largest wells have been found on the crests of anticlinal axes, one of the most notable being the Sheffield well, drilled in 1875. This one is remarkable from the great pressure of the gas, which rendered the drilling difficult. A vein of salt water, passed through at 418 feet, was allowed to leak into the well; the gas sand, 45 feet thick, was struck at 1,350 feet, when the gas, being suddenly relieved from pressure, as it expanded into the well absorbed heat from the water so rapidly as to form a core of ice about 200 feet deep, which nearly stopped up the bore.

The average pressure of gas in the Pittsburg district is from 100 to 200 lbs. per square inch. At Carnegie Brothers' steel works, nine miles

* "Science," vol. v. p. 474.

from the well at Murraysville, it is 75 lbs. per square inch. The highest pressure recorded as measured is 750 lbs. per square inch.

The average calorific value of natural gas is not yet fully determined, but some experiments have shown that about 1,000 cubic feet of the gas, weighing about 38 lbs. Av., are equal in heating power to about 55 lbs. of Pittsburg bituminous coal, or about 20,000 cubic feet to the ton.

As regards its chemical composition, the following is an analysis of the gas made by Dr. G. Hay for the Natural Gas Commission, and published in the "Engineering and Mining Journal," vol. xxxix. p. 247 :—

	Per cent.
Carbonic anhydride	0.00
Carbonic oxide	1.00
Heavy hydrocarbons	0.50
Marsh gas	95.20
Hydrogen	2.00
Oxygen	1.30
Nitrogen	0.00
	100.00

This, however, does not quite agree with the analyses given by Mr. S. A. Ford, chemist to the Edgar Thomson Steel Works, who communicated the following examination of the gas, through Mr. Carnegie, to the Iron and Steel Institute :—

"So much has been claimed for natural gas as regards the superiority of its heating properties as compared with coal, that some analyses of this gas, together with calculations showing the comparison between its heating power and that of coal, may be of interest.

"These calculations are, of course, theoretical in both cases, and it must not be imagined that the total amount of heat either in a ton of coal or 1,000 cubic feet of natural gas can ever be fully utilized. In making these calculations, I employed as a basis what, in my estimation, was a gas of an average chemical composition, as I have found that gas from the same well varies continually in its composition. Thus, samples of gas from the same well, but taken on different days, vary in nitrogen from 23 per cent. to *nil*, carbonic acid from 2 per cent. to *nil*, oxygen from 4 per cent. to 0.4 per cent., and so with all the component gases.

"Before giving the theoretical heating power of 1,000 cubic feet of this gas, I will note a few analyses. The first four are of gas from the same well; samples taken on the same day that they were analysed. The two last are from two different wells in the East Liberty district. I also give a few analyses of Siemens' producer gas. The immense heating-power of the natural gas over the Siemens' may be seen at a glance when compared bulk for bulk.

Analyses of Natural Gas.

	No. 1.	No. 2.	No. 3.	No. 4.	No. 5.	No. 6.
When tested	10/28/84	10/29/84	11/24/84	12/4/84	10/18/84	10/25/84
Carbonic acid	.8%	.6%	Nil	.4%	Nil	.30%
Carbonic oxide	1.0	.8	.58%	.4	1.00%	.60
Oxygen	1.1	.8	.78	.8	2.10	1.20
Olefiant gas	.7	.8	.98	.6	.80	.60
Ethylic hydride	3.6	5.5	7.92	12.30	5.20	4.80
Marsh gas	72.18	65.25	60.70	49.58	57.85	75.16
Hydrogen	20.02	26.16	29.03	35.92	9.64	14.45
Nitrogen	Nil	Nil	Nil	Nil	23.41	2.89
Heat units	728,746	698,852	627,170	745,813	592.380	745,591

Analyses of Siemens' Producer Gas. (*See* vol. xi. p. 300, "*Transactions of American Institute of Mining Engineers.*")

Carbonic acid .	3.9°/o	8.6°/o	9.3°/o	1.5°/o	6.1°/o
Carbonic oxide .	27.3	20.0	16.5	23.6	22.3
Hydrogen . .	—	8.7	8.6	6.0	28.7
Marsh gas . .	1.4	1.2	2.7	3.0	1.0
Nitrogen . .	67.4	61.4	62.9	65.9	41.9
Heat units .	93,966	97,184	99,074	114,939	164,164

"We will now show how the natural gas compares with coal, weight for weight, or in other words how many cubic feet of natural gas contains as many heat units as a given weight of coal—say a ton.

"In order to accomplish this end, we will be obliged, as I have said before, to assume as a basis for our calculations what I consider a gas of an average chemical composition, viz.:—

Carbonic acid	.60 per cent.
Carbonic oxide	.60 ,,
Oxygen	.80 ,,
Olefiant gas	1.00 ,,
Ethylic hydride	5.00 ,,
Marsh gas	67.00 ,,
Hydrogen	22.00 ,,
Nitrogen	3.00 ,,

"Now by the specific gravity of these gases we find that 100 litres of this gas will weigh 64.8585 grams, thus—

Marsh gas	67.0 litres	weighs	48.0256 grams
Olefiant gas	1.0	,,	1.2534 ,,
Ethylic hydride . . .	5.0	,,	6.7200 ,,
Hydrogen	22.0	,,	1.9712 ,,
Nitrogen	3.0	,,	3.7632 ,,
Carbonic acid	.6	,,	1.2257 ,,
Carbonic oxide	.6	,,	.7526 ,,
Oxygen	.8	,,	1.1468 ,,
Total . . .			64.8585

"Then if we take the heat units of these gases we will find—

Marsh gas	48.0256 grams	contains	627,358 heat units
Olefiant gas . . .	1.2534	,,	14,910 ,,
Ethylic hydride . . .	6.7200	,,	77,679 ,,
Hydrogen	1.9712	,,	67,929 ,,
Carbonic oxide . . .	.7526	,,	1,808 ,,
Nitrogen	3.7630	,,	— ,,
Carbonic acid . . .	1.2257	,,	— ,,
Oxygen	1.1468	,,	— ,,
	64.8585	,,	789,694 ,,

64.8585 grams are almost exactly 1,000 grains, and 1 cubic foot of this gas will weigh 267.9 grains, then the 100 litres or 64.8585 grams or 1,000 grains are 3.761 cubic feet.

"3.761 cubic feet of this gas contains 709,694 heat units, and 1,000 cubic feet will contain 210,069,604 heat units.

"Now 1,000 cubic feet of this gas will weigh 265,887 grains, or in round numbers 38 lbs. avoirdupois.

"We find that 64.8585 grams, or 1,000 grains of carbon, contain 524,046 heat units, and 265,887 grains, or 38 lbs. of carbon, contain 139,398,896 heat units. Then 57.25 lbs. of carbon contain the same number of heat units as a 1,000 cubic feet of the natural gas—viz., 210,069,604.

"Now, if we say that coke contains in round numbers 90 per cent. carbon,

then we will have 62.97 lbs. of coke equal in heat units to 1,000 cubic feet of natural gas.

"Then if a ton of coke, or 2,000 lbs., cost 10*s*., 62.97 lbs. will cost 4 pence, or 1,000 cubic feet of gas is worth 4 pence for its heating power.

"We will now compare the heating power of this gas with bituminous coal, taking as a basis a coal slightly above the general average of the Pittsburg coal, viz.:—

Carbon	82.75 per cent.
Hydrogen	5.31 ,,
Nitrogen	1.04 ,,
Oxygen	4.64 ,,
Ash	5.31 ,,
Sulphur	.95 ,,

"We find that 38 lbs. of this coal contains 146,903,820 heat units. Then 54.4 lbs. of this coal contains 210,069,640 heat units, or 54.4 lbs. of coal is equal in its heating power to 1,000 cubic feet of natural gas. If our coal cost us 5*s*. per ton of 2,000 lbs., then 54.4 lbs. will cost 1.632 pence, and 1,000 cubic feet of gas will be worth for its heat units 1.632 pence.

"As the price of coal increases or decreases, the value of the gas will naturally vary in like proportions. Thus, with the price of coal at 10*s*. per ton, the gas will be worth 3.264 pence per 1,000 cubic feet.

"If 54.4 lbs. of coal be equal to 1,000 cubic feet of gas, then one ton, or 2,000 lbs., will be equal to 36,764 cubic feet, or 2,240 lbs. of coal will be equal to 40,768 cubic feet of natural gas.

"If we compare this gas with anthracite coal, we find that 1,000 cubic feet of gas is equal to 58.4 lbs. of this coal, and 2,000 lbs. of coal is equal to 34,246 cubic feet of natural gas. Then if this coal cost 26*s*. per ton, 1,000 cubic feet of natural gas will be worth 9½ pence for its heating power.

"In collecting samples of this gas I have noted some very interesting deposits from the wells. Thus, in one well the pipe was nearly filled up with a soft greyish-white material, which proved on testing to be chloride of calcium. In another well, soon after the gas vein had been struck, crystals of carbonate of ammonia were thrown out, and upon testing the gas I found a considerable amount of that alkali, and with this well no chloride of calcium was observed until about two months after the gas had been struck.

"In these calculations of the heating power of gas and coal, no account is of course taken of the loss of heat by radiation, &c. My object has been to compare these two fuels merely as regards their actual value in heat units."

A practical test* of the fuel value of natural gas has been carried out by the Westinghouse Air-brake Company, who possess valuable gas wells at Pittsburg. Taking the usual "best" quality of Pittsburg coal, it was found that its evaporating duty in a particular boiler was 10.38 lbs. of water per lb. of the solid fuel. With the same boiler 1.18 cubic feet of natural gas evaporated 1 lb. of water; whence it follows that 1 lb. of coal is equivalent to 12.25 cubic feet of gas, or that 1,000 cubic feet of the gas were as good as 81⅝ lbs. of coal. According to calorimetric tests, 55.4 lbs. of coal contain the same number of heat units as 1,000 cubic feet of gas, so that the practical test was better for the gas than might have been expected. Even with this good result, however, as the coal in question is worth only about five shillings per ton, or 3*d*. per cwt., the fuel value of the natural gas supply used in competition with it can only be about 2*d*. per 1,000 cubic feet. It is evident that the expenses of winning, piping, and managing a natural gas supply in the neighbourhood of Pittsburg must be very low to pay a profit upon a service sold upon this valuation. It is stated, however, that there is a greater economy in the use of natural gas, as compared with coal,

* See "Mechanical World," Dec. 17, 1886; "Jour. Iron and Steel Inst.," vol. i. 1887, pp. 366, 418.

for domestic purposes and small industrial establishments, which is independent of its advantages when used for purposes for which freedom from smoke is a recommendation.

The freedom of the gas from sulphur has been an important element in its metallurgical value.

At first, on account of its abundance, natural gas was burned without regard to waste, but economical appliances are being introduced. Messrs. Carnegie Bros. have attached to each puddling furnace a small regenerative appliance, which is found to be effectual in saving gas. The principle of the argand burner has also been applied to the burning of this gas by Mr. E. J. Dashbach,* with the result that furnaces to which it has been applied work with greater speed.

It is said† that, when this gas is used in ordinary open-hearth furnaces, it is liable, on being heated, to decompose, with the formation of a very pure, hard, and glossy coke, which chokes up the chequer work of the regenerators.

LIQUID FUEL.

The discovery of large quantities of petroleum in America, and the accumulation of dead oil in this country (owing to the temporary abandonment of the creasoting process), drew attention to the employment of these substances as liquid fuels. An American Commission appointed to investigate the question of the employment of petroleum as fuel reported that it was more than twice as effective as anthracite for steam raising, and methods were soon proposed for the use of liquid fuel, principally for steam raising.

The following table (from "Facts about Oil," by Mr. John P. Zane) shows the number of producing wells, the amount of production, the price of oil per barrel at the wells, consumption and stock on hand in America for the last twenty-eight years:—

Year.	No. of Wells.	Amount of Production.	Average Price for the Year.	Consumption.	Stock.
1859	1	2,000	$20.00		
1860	200	200,000	9 60		
1861	200	2,110,000	2.73		
1862	400	3,055,000	1.06		
1863	500	2,610,000	3.15		
1864	1,000	2,130,000	9 87½		
1865	1,000	2,721,000	6.59		
1866	900	3,732,000	3.74		
1867	900	3,583,000	2.41		
1868	1,000	3,716,000	3.62½		
1869	1,000	4,351,000	5.63¾		
1870	1,044	5,371,000	3.89	5,156,528	534,626
1871	1,472	5,531,000	4.34	5,553,626	532,000
1872	1,201	6,357,000	3.64	5,804,577	1,084,423
1873	2,361	9,932,000	1.83	9,391,226	1,625,157
1874	1,350	10,883,000	1.17	8,802,513	3,705,639
1875	2,385	8,800,000	1.35	8,956,439	3,550,200
1876	2,960	9,015,000	2.56¼	9,740,461	2,824,730
1877	3,954	13,043,000	2.42	12,739,902	3,127,827
1878	3,018	15,367,000	1.19	13,879,538	4,615,299
1879	2,889	19,827,000	85⅞	15,961,809	8,470,190
1880	4,194	26,048,000	94½	15,590,040	18,938,430
1881	3,848	27,238,000	85⅝	29,146,726	25,019,704
1882	3,269	30,460,000	78¼	21,883,098	34,596,612
1883	2,886	24,300,000	1.05¾	22,006,612	36,800,000
1884	2,309	23,500,000	83¼	23,500,000	36,800,000
1885	2,857	20,900,000	88	23,900,000	33,800,000
1886	3,525	26,150,000	71¼	26,700,000	33,000,000

* "Engineering and Mining Journal," vol. xli. p. 90. † "Iron Age," vol. xxxv. No. 17.

Admiral Selwyn* very early recognized the advantages possessed by a fuel in this concentrated and easily handled form, especially for use in steam ships and ships of war, and has repeatedly advocated its employment. Professor Rankine† also wrote on this subject, and he and Dr. B. H. Paul‡ investigated the theoretical efficiency of liquid fuels, calculating the evaporative power of the hydrocarbons as the sum of that of the hydrogen and carbon in each, as found by ordinary chemical analysis. It is to be observed, however, that the theoretical efficiency, as thus calculated, is not always to be depended on. When hydrocarbons are formed, there is a loss of energy in the act of formation, and the law of this loss has not yet been accurately ascertained.

Moreover, numerous hydrocarbons exist whose properties are different, although their composition is the same, and these different hydrocarbons give out different amounts of heat on combustion, which amounts do not (as in the case of other hydrocarbons also) always agree with the calorific power, calculated as the sum of that of their elements. Thus, whilst marsh gas yields by experiment 2,672 units per lb. *less* than that due by calculation from its elements, both olefines and acetylene yield a much larger amount of heat than is estimated from their chemical constituents.

Rankine adopted as his unit the weight of combustible required to evaporate 1 lb. of water at 212° F., under an atmospheric pressure of 14.7 lbs. per square inch. This is equal to 966 British thermal units (or 537 French or centigrade units), or 966 times the quantity of heat that raises 1 lb. of water from 39° to 40° F.

His observations were reduced as follows:—

Let E be the corrected and reduced evaporation,
ϵ the weight of water actually evaporated,
T_1 the standard boiling point (say 212° F.),
T_f the temperature of the feed water,
T_b the actual boiling point observed; then

$$E = \epsilon \left\{ 1 + \frac{T_1 - T_f + 0.3(T_b - T_1)}{966 \text{ F. or } 537 \text{ C.}} \right\}.$$

The result shows the number of times its own weight of water which a fuel would evaporate at the standard temperature if there were absolutely no waste of heating power, but, as there is always more or less waste, the efficiency of a furnace is expressed by the ratio $\frac{E' \text{ (available)}}{E \text{ (total)}}$, which, were there no loss, would be = 1.

To ascertain the loss of units of evaporation by the waste gases, Rankine proposed the formula:—

$$\text{Loss by chimney} = \frac{1 + A'}{4000} Tc \text{ (F.°)},$$

where $1 + A'$ denotes the weight of burnt gas per unit weight of fuel, and Tc (F.°) the temperature of chimney gases above that of the atmosphere. For ordinary coal $1 + A'$ ranges from 13 to 25 (19 being a medium quantity), and for hydrocarbon oils it is 16.3, if no excess of air is necessary above what is required for the oxidation of the fuel.

Taking coal examples with chimney draught (600° F. being the temperature of waste gases necessary to produce draught), where

$1 + A'$	= 13	...	19	... 25
Tc	= 600°	...	600°	... 600°
Volume of gases in cubic feet .	= 325	...	475	... 625
Loss of evaporative power .	= 1.95	...	2.85	... 3.75

* "Min. Proc. Inst. C.E.," vol. xxix. p. 194; "Jour. Royal United Service Institution," 1865, vol. ix. p. 66, "Trans. Inst. Naval Architects," 1868, 1869, 1870, 1885.
† "Jour. Roy. U.S. Inst.," vol. xi. p. 218. ‡ "Jour. of the Society of Arts," April 17, 1868.

The theoretical evaporative power of hydrogen and carbon (under various conditions) is given by Rankine as follows:—

	Oxygen per Unit of Weight.	Air per Unit of Weight.	Units Evaporated.
Hydrogen	8	36	64.2
Carbon, solid	$2\frac{2}{3}$	12	15 0
Carbon, solid, half oxidized	$1\frac{1}{3}$	6	4.5
Carbon gas in $2\frac{1}{3}$ parts carbonic oxide	$1\frac{1}{3}$	6	10.5
Carbon, gaseous (calculated)	$2\frac{2}{3}$	12	21.0

The figures for carbon apply to charcoal carbon. Rankine also assumed, in his calculation, that six units became latent in the operation of making gaseous from solid carbon.

Dr. Paul calculated the evaporative power of the hydrocarbons as the sum of that of the hydrogen and carbon supposed to exist in each, on the assumption that, when burned with the minimum of air for perfect combustion, each lb. of carbon will evaporate 11.359 lbs., and each pound of hydrogen 41.895 lbs. of water at 60° F. into steam at 212° F. His results are contained in the following table. Column V. gives the evaporative duty when the furnace gases are discharged at 600° F. above the temperature of the air supplied to the furnace.

	I. Carbon.	II. Hydrogen.	III. Oxygen.	IV. Evaporative Power: lbs. Water at 212° F.	V. Evaporative Duty: lbs. Water at 60° F.
Phenol	76.60	6.40	17.00	12.2437	10.5025
Cresol	77.70	7.41	14.82	13.0096	11.1632
Naphthalin	95.75	6.25	—	15.4350	13.0751
Anthracene	94.38	5.62	--	15.2417	13.2675
Xylol	90.56	9.44	—	16.5866	14.2415
Cumol	90.00	10.00	—	16.7838	14.4126
Cymol	89.55	10.45	—	16.9422	14.5500

In estimating the theoretical evaporative efficiency of different combustibles from their chemical constitution, Rankine proposed the formula, $E = 15C + 64H - 8O$, but pointed out that it gives a slightly higher value for evaporative power than experiment showed. To calculate the amount of air necessary for the combustion of any fuel, he used the rule

$$A = 12C + 36H - 4\tfrac{1}{2}O.$$

The quantity actually used, is, however, generally much in excess of that found by this rule. Rankine announced the following results obtained by the use of these rules:—

Description of Fuels.	Chemical Composition. C.	H.	O.	A.	E.	Evaporation due to C.	Evaporation due to $H - \frac{O}{8}$
Charcoal	.93	0	0	11.5	14.0	14.0	0
Coke	.88	0	0	10.6	13.2	13.2	0
Rock oils $C_{18}H_{20}$	.84	.16	0	15.75	22.7	12.7	10.0
Rock oils $C_{20}H_{20}$	.85	.15	0	15.65	22.5	12.66	9.84
Coal	.87	.05	.04	12.1	15.9	13.05	2.85
,,	.85	.05	.06	11.7	15.5	12.75	2.75
,,	.75	.05	.05	10.6	14.1	11.25	2.85
Ethylene, C_2H_4	.75	.25	0	18.0	27.3	11.25	16.05
Acetylene, C_2H_2	.85	.14	0	15.43	22.1	12.9	9 2
Peat, dry	.56	.06	.31	7.7	10.0	8.5	1.5
Wood, dry	.58	.05	.40	6.0	7.5	7.5	0

Paul arrives at the *effective* heat as follows :—

COMBUSTION OF 1 LB. OF CARBON.

	Heat Units.	Equivalent Evaporation of Water.	
		At 212° F.	At 60° F.
Total heat of combustion	14,500	15	
Available heat . . .	14,500		
Waste of furnace gases at 600° F. . .	3,480	3.6	
Effective heat	11,020	11.4	9.8

COMBUSTION OF 1 LB. OF HYDROGEN.

Total heat of combustion	62,032	64.2	
Latent heat of water vapour . . .	8,695		
Available heat . . .	53,337		
Waste heat of furnace gases . . .	11,520	11.9	
Effective heat	41,817	43.3	38.

The following is the calculation per lb. for two typical hydrocarbons having the composition indicated :—

A.

Carbon.	Hydrogen.		Total Heat of Combustion.	Equivalent Evaporation of Water.	
				At 212°.	At 60°.
.86		× 14,500 =	12,470		
	.14	× 62,032 =	8,684		
			21,154	21.9	18.8
Furnace Gases.			**Heat Units in Furnace Gases.**		
		lbs.			
Carbonic acid		3.16	411		
Water vapour		1.26	359		
Nitrogen		11.45	1,683		
Surplus air		14.37	2,124	2.2	
		30.74	4.577	4.8	
Total heat of combustion			21,154		
Latent heat of water vapour . . .			1,217	1.3	
Available heat . . .			19,937		
Waste in furnace gases			4,577	4.8	
Effective heat			15,360	15.8	13.6
Theoretical evaporating power				21.9	
Relative efficiency, taking carbon as 1, = 1.39.					

B.

Carbon.	Hydrogen.		Total Heat of Combustion.	Equivalent Evaporation of Water. At 212°.	At 60°.
·75		× 14,500 =	10,775		
	.25	× 62,032 =	15,508		
			26,283	27.1	23.1
Furnace Gases.			**Heat Units in Furnace Gases.**		
		lbs.			
Carbonic acid		2.75	358		
Water vapour		2.25	641		
Nitrogen		13.39	1.968		
Surplus air		17·39	2,483	2.6	
		35·78	5,450		
Total heat of combustion . . .			26,283		
Latent heat of water vapour . .			2,174	2.2	
Available heat . . .			24,109		
Waste in furnace gases			5,450	5.6	
Effective heat			18,659	19.3	16.6
Theoretical evaporating power				27.1	
Relative efficiency, taking carbon as 1, = 1.69.					

Paul estimates that, on the whole, 1 lb. of hydrocarbon fuel is not likely in practice, and on the average, to evaporate more than 16 lbs. of steam; but, if only just sufficient air for combustion were supplied (*i.e.*, half the quantities estimated for above), the effect might in case A. be increased by 13 or 14 per cent. On the latter understanding, also, Paul takes dead oil as on an average capable of evaporating 13 lbs. of water from 60° F. to steam at 212 F.

Storer has estimated the theoretical evaporative power of a pure petroleum containing 86 per cent. of carbon at rather more than 18 lbs. He also states that a kilo. of crude petroleum evaporates 10.36 kilos. of water against 5.1 kilos. evaporated by the same weight of anthracite.

The following figures are due (1866–9) to Deville :—

	Heat Units.
Heavy oil from West Virginia	10,180
Light „ „ „	10,223
„ „ Pennsylvania	9,963
Heavy „ Ohio	10,399
Oil from Java (Rembang)	10,831
„ „ (Cheribon)	9,593
„ „ (Soerabaya)	10,183
Petroleum from Schwabwiler (Alsace)	10,458
„ „ E. Galicia	10,005
„ „ W. „	10,235
Crude shale oil from Autun (France)	9,950

As the above oils vary considerably in their composition—the Galician oils more particularly—these results can have but a general value.

As regards suitability for liquid fuel, it is to be observed that most tars and petroleum admit of combustion in suitable plant; but those liquid fuels are least valuable which contain most oxygen and nitrogen. Sulphur,

which is, of course, an objectionable constituent, always occurs in coal tars but is frequently absent from petroleum and petroleum residues.

The rapid development, since the year 1876, of the enormous stores of petroleum existing at Baku and the Caucasus district, and the consequent vast accumulations of naphtha refuse there as the result of refining the natural oil, have led to a greatly extended employment of liquid fuel in South-east Europe—principally in South-east Russia.

Some idea of the extent of this oil-producing region may be derived from the following figures:—"In the beginning of the present century, the estimated yield from the springs at Baku was about 4,000 tons annually, and of that quantity the larger portion went to Persia. From 1813 to 1872, the raising of the oil was made a State monopoly, and production did not develop to any extent. Still, from 1832 to 1850 the average yearly output was 1,000,000 gallons, and in the next ten years the rate was increased to 2,000,000 gallons. By 1872, the production had grown to 7,679,905 gallons. At this time the product of the American oil fields began to flood, not only Europe, but Russia, and the Russian Government, becoming alive to the importance of the Baku district, abolished the monopoly." * By the end of 1873, the output had risen to 19,757,857 gallons, by 1874 to 24,313,215 gallons, and by the close of 1875 to 29,045,215 gallons. The output since 1875 has been as follows:—

1876	1,400,000 barrels or	56,000,000	gallons
1877	2,000,000 "	80,000,000	"
1878	2,500,000 "	100,000,000	"
1879	3,000,000 "	120,000,000	"
1880	to	0	
1881	4,000,000 "	160,000,000	"
1882	5,000,000 "	200,000,000	"

An area of about 4½ square miles forms the nucleus of the oil-bearing region of the Caucasus. The naphtha-bearing beds consist of sand, calcareous clays, marls, and, in places, compact sandstone, often of great thickness, and penetrated by bands of pyrites. As in Pennsylvania, the naphtha is in some places associated with salt water, which gives much trouble in driving bore holes. The plateau is on a level of about 140 feet above the surface of the Caspian, and a depth of 700 feet below that great lake has been reached by boring.

Petroleum, however, is found not at Baku only, but, according to Mr. C. Marvin, it exists throughout the whole extent of the Caucasus, under the Caspian to Tcheleken, and again in the Little and Big Balkans beyond, a distance of over 1,200 miles.

Professor Romanoffsky has proposed a method of boring for this oil which avoids the outcrops and the anticlinal bends of the oil-bearing strata, and arranges the bore holes to strike the beds at not less than 400 feet below the outcrop. When the oil is struck, the pressure of gas, which occurs here as in America, forces the oil up, forming fountains of varying size. The gas pressure has been found to range between 50 lbs. and 300 lbs. per square inch, and, under the higher pressures, stones, clay, and sand are often projected out of the bore holes along with the oil, which breaks up into fine spray and is often carried far by the wind. In the year 1883 two fountains played simultaneously to a height of between 250 and 350 feet, and during 1887 one has, it is said, reached a height of 400 feet. Mr. Thomas Urquhart † observes that cases occur almost annually of petroleum gushing forth from wells under great pressure and spouting to a height of from 50 to 75 feet, with a diameter at the issuing point of from 10 to 15

* Mr. C. Marvin, "Baku, the Petrolia of Europe."

† On the Use of Petroleum Refuse as Fuel in Locomotives, "Proc Inst M.E.," 1884, p. 272.

inches. Such a fountain flows uncontrollably for weeks together, flooding all the immediate vicinity and forming lakes of petroleum. This oil is called "lake petroleum," and it loses, after a few days' settling, the more volatile portion of its constituents by evaporation.

Vast quantities of oil have been lost from the breaking forth of fountains before any reservoirs had been constructed. Some of the fountains are intermittent, playing for from two to three hours at a time, and then ceasing for a day or two. These are the most lucrative, as they give time for storing their produce. Continuous fountains after a time become intermittent, finally subsiding into ordinary wells. A continuous fountain may yield over 3,300 tuns of oil, and require the labour of one hundred men to collect and store its product. The daily yield is worth about £100, the cost of labour being from £15 to £20.

At Balaxna (Black Town), near Baku, there are many large distilling establishments for manufacturing kerosene, benzene, photogen, &c., from crude petroleum. The bye-products or refuse are used for the manufacture of lubricating oils, but more generally as fuel.

In Russia, the quantity of refuse in proportion to the distilled kerosene is very great; the finest kerosene amounts to about 25 per cent. only of the original weight of crude oil used, and ordinary commercial kerosene to only about 30 per cent., the remaining 70 or 75 per cent. being available for fuel. In America the results obtained from native petroleum are different, the amount of ordinary kerosene for illuminating purposes produced from the Pennsylvania crude oil being from 70 to 75 per cent. of the crude oil used. There is, however, very little difference in the percentage composition of the crude oils of the two countries, as the following statement, due to M. Goulishambaroff,* shows:—

	Sp. Gr.	Composition.			Heating Power. British Units.	Theoretical Evaporation per lb. at 8 Atmospheres. lbs.
		Carbon.	Hydrogen.	Oxygen.		
Russian crude petroleum oil { Light	.884	86.3	13.6	.1	22,628	17.4
Russian crude petroleum oil { Heavy	.938	86.6	12.3	1.1	19,440	16.4
Russian naphtha refuse	.928	87.1	11.7	1.2	19,260	16.2
Pennsylvanian crude heavy petroleum oil	.886	84.9	13.7	1.4	19,210	16.2

Whilst America and Russia are at present the chief oil-producing countries in the world, there are evidences that stores of natural petroleum are widely distributed over the globe. Oil has been already found in Roumania, Hanover, Burmah, Australia, Galicia, Egypt, India, New Zealand, California, and Africa, and will probably be discovered in other countries also. Natural bitumen exists in the West Indies. The question of supply has a most important bearing on the use of liquid fuel, as it is only the existence of abundance of this fuel which can regulate the price of it to a point at which it can be used with advantage instead of coal.

In addition to the products from natural petroleum, the visible sources of supply are—(1) the tar from gasworks; (2) that which is recovered from coal used in blast-furnaces, coke-ovens, and gas-producers; and (3) products from the mineral-oil industry. The first of these is not capable of much extension, at least in this country, but the second may be increased, as it is only quite recently that much attention has been directed to the recovery of bye-products from the use of coal in manufacturing operations. The mineral oil industry has been largely developed in Scotland during recent years,

* *Compt. Rend.*, tome lxix. pp. 442-453.

the amount of shale distilled having been, in 1871, 800,000 tons, producing 25,000,000 gallons of crude oil, whilst in 1885, 2,090,000 tons of shale were distilled, producing 62,712,000 gallons of crude oil. In connection with this method of obtaining oil, Admiral Selwyn has mentioned that in several parts of England—particularly on the southern coasts—there is a practically unlimited supply of shale, known as "Kimmeridge clay," which is said to yield 40 gallons of crude oil per ton. These combined sources of supply make it appear that there is less fear now than formerly that the demand can exceed the supply of liquid fuel. Its general introduction therefore depends principally on the price which can be paid for it without counterbalancing its advantages over coal. On this point there is much diversity of opinion, founded upon the view which is taken of its comparative advantages and upon the results obtained in trials of long or short duration. The solution of the matter largely depends on the evaporative or heat-producing effect which is realized by the use of this fuel; but even with a small margin of *economy* in respect of that effect, there are special circumstances connected with the use of fuel in steamships, and especially in ships of war, which cause the other qualities of liquid fuel to weigh heavily in its favour.

Methods of Using Liquid Fuel.—The various methods of using liquid fuel which had been introduced prior to the year 1878 were classified by the late Harrison Aydon ("Min. Proc. Inst. C.E.," vol. lii. p. 177, &c.*).

1. *Injection with compressed air.*—In this plan (patented by W. Bridges Adams in 1863) the oil was injected through a double nozzle from a tank by means of compressed air, a layer of incandescent coke being kept on the furnace bars. This is evidently the forerunner of the method introduced by Mr. Tarbutt in 1885.

2. *Percolation through a porous bed.*—The liquid fuel accompanied by heated air percolates upwards through a porous bed placed in the bottom of the furnace space. This system was introduced by C. J. Richardson in 1864, and improved in 1866 by the introduction of steam with the air supply.

In Weir and Gray's modification of this plan, a porous bed was placed at the level of the fire-bars, the oil coming in through a perforated pipe at its lower surface; and a jet of steam, carrying in air along with it, was introduced above the furnace door. Aydon places St. Clair Deville's plan as used in French locomotives in this class, although it differs from Richardson's to some extent. The oil was allowed by Deville to trickle through numerous small channels on to the upper surface of heated fire-bricks placed in the bottom of the ash-pit of the furnace, air being admitted through a small damper at the same level.

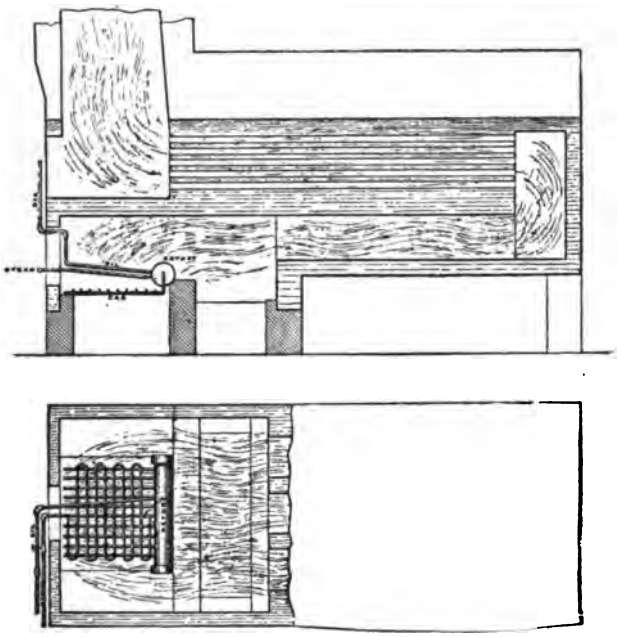
3. *Vaporization.*—The oil is fed into a small retort lying in, and heated by, the furnace; the gas which is thus formed issues through numerous openings in jets, which are ignited. This plan was introduced in America by Col. Foote in the United States gunboat *Palos*, and is shown in Fig. 183 (p. 301), and a similar plan was patented (in 1865 and 1867) by Simm and Barff, of Glasgow. In Col. Foote's plan, the retort was placed at the fire-bridge; small pipes, carrying 125 jets or burners, were led from the retort along the lines of the fire-bars; and steam was admitted into the furnace, superheated in a zigzag coil placed over the gas jets.

4. *Steam-spray injection.*—A jet of steam, superheated if possible, is used to inject the liquid fuel into the furnace, at the same time breaking it up into the finest spray, turning it either wholly or partially into vapour, by the heat of the steam (and partly by the radiated heat of the furnace), and mixing it with the air supply, which is drawn in as an induced current.

* See also O. C. D. Ross, vol. xl. pp. 150–161; vol. xlii. p. 336.

This, in some form, has been the most successful, as it is the most convenient, method of applying oil-fuel. It has been combined with a variety of arrangements in the combustion chamber—as, for instance, a layer of incandescent fuel covering the fire-bars; a portion of the fire-bars covered with fire-bricks and the rest with fuel; a combustion chamber entirely of fire-brick, all fire-bars being removed. The late Harrison Aydon was the first to introduce a practicable method of this class, which he patented with Messrs. Wise and Field in 1865-1867.

FIG. 183.



Colonel Foote's American Furnace, as tried in U.S. gunboat *Palos*.

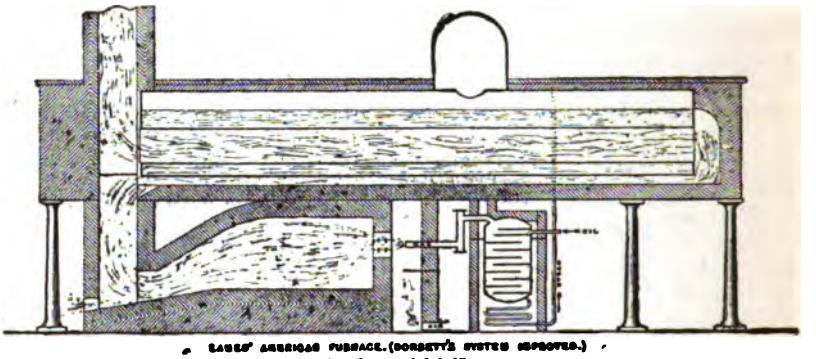
James Donald, of Glasgow, patented in 1868 a modification of the same plan, and another form was in 1874 applied by Urquhart to locomotives in Russia. Many varieties of injectors and nozzles have been subsequently introduced, but the successful use of oil on this system depends to a large extent on the proper distribution of brickwork in the combustion chamber, so that what is required is a combination of the best nozzle with the best construction of furnace.

5. *Vaporization in a separate (external) boiler or retort.*—Here the retort is not heated in the furnace, and the oil is vaporized by independent heating of the retort, or by the heat of steam passed into contact with the oil, or by a combination of both methods. The first was Dorsett's plan, patented in 1868 and 1869; the second, a modification patented in America by Dr. C. J. Eames in 1875.

Eames's generator was of wrought iron, similar to an egg-shaped boiler placed on end. It was divided by horizontal iron shelves, projecting alternately from each side, nearly across the generator. The generator was placed over a fireplace in which a coil of pipes was arranged as a superheater for the steam, which, after passing through the coil, entered the generator at the bottom. The oil was admitted by a pipe at the top, and, running on to

the top shelf, trickled across it and dropped to the shelf below, repeating this until the other shelves were passed in succession. A large surface of oil was thus exposed to the action of the superheated steam, which, entering below, passed upwards through the generator. The effect of contact between the steam and oil at the high temperature employed was that they mutually decomposed each other, and issued as gas at the top of the generator through pipes with regulating valves, from which the gas passed to a combustion chamber. Air for combustion was admitted here, and the flame then entered the furnace. Fig. 184 shows this arrangement of Eames' as applied to an iron-heating furnace with a steam boiler above, which was heated by the waste heat.

Fig. 184.

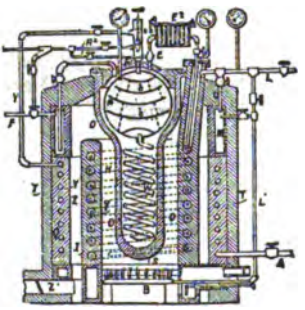


EAMES' AMERICAN FURNACE. (DORSETT'S SYSTEM ADOPTED.)

The manufacture of gas from oil* has received much attention in recent years, although chiefly in connection with its application to lighting. The production and quality of this gas are, however, of great interest in connection with the use of liquid fuel, and, it is probable, will influence the methods of using oil to a large extent.

In the apparatus used by Pintsch, Keith, and others, oil is simply dropped into a red-hot retort and volatilized in this way, from about 80 to 150 cubic feet of purified gas per gallon of oil being obtained, according to the quality of oil and the temperature employed.

Fig. 185.



In a form of apparatus made by Messrs. Rogers, of Watford, the oil is injected as spray into the red-hot retort by means of a steam jet, and from 110 to 120 cubic feet (after condensation and purification) of a very rich gas are obtained per gallon of oil.

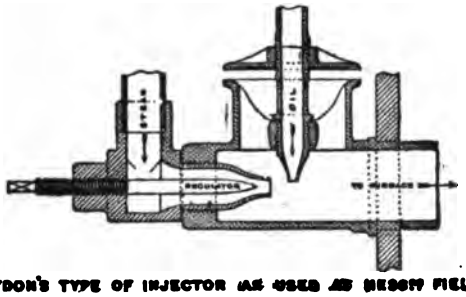
Fig. 185 illustrates an apparatus patented by Mr. J. B. Archer, of Washington, America, for the production of oil gas for furnaces. According to Archer's method of production, steam superheated to about 1000° F. is made to pass through an injector and draw with it a quantity of oil, which becomes mixed with the steam. The mixture is further heated to about 1300° F. when it receives an additional quantity of oil, and finally this mixture is heated to about 2400° F., whereby it is

* H. E. Armstrong, "Jour. Soc. Chem. Indus.," vol. iii. p. 462; "A Manual of the Manufacture of Gas from Tar Oil and other Liquid Hydrocarbons," by W. Burns, C.E. (London: Spon); "A Manuelette of Destructive Distillation," by E. J. Mills, D.Sc., F.R.S.

converted into permanent gas. The apparatus comprises three concentric cylindrical casings, of which the outermost is enclosed in brickwork T, and consists of a superheater Q, having within it a helical passage Y and a retort M, in which the gaseous mixture undergoes its final heating. Separated by an annular flue space Z is the second casing V, of metal, formed with a helical passage I, containing a helical pipe H of smaller diameter. In the flue space D is suspended the primary retort O, consisting of a vertical cylinder closed at its bottom S, which is directly heated by a circle of gas-jets B. The hot gases from these jets ascend through D, descend by Z, and pass by the flue Z^1 to the chimney. Within the enlarged part of the primary retort O is a spherical shell P, divided by perforated partitions *b*, from which a helical pipe W extends down nearly to the bottom of the primary retort, where it terminates with an open mouth. Steam supplied by a pipe A enters the lowest coil of the superheater Y, and flowing upwards by a pipe Y^1 through the injector Y^2, to which the oil-supply pipe R is connected, draws in the oil, which passes with the steam through the pipe R^1 into the spherical shell P. Here the oil and steam are thoroughly mixed, and the mixture passes down the helical pipe W, up the body of the retort, and out at the top by a pipe E to the external mixing chamber E^1, where an additional quantity of oil is supplied to it by a branch R^2 from the oil pipe R. From the mixing chamber E^1, the mixed fluid enters the inner pipe H of the helical retort V, flows along its convolutions, out at its lower open end, back along the convolutions of the helical passage I containing the pipe, thence by the pipe U into the final retort M, whence it passes away by the pipe F as a permanent gas. By the pipe L gas can be led off without passing through the retort M, and the pipe L^1 of the burner B can be supplied either from L or by a branch from the retort M.

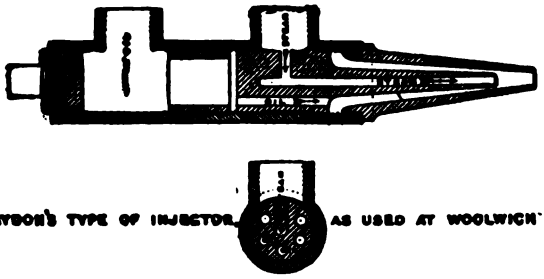
Figs. 186–190 illustrate different forms of liquid fuel injectors introduced successfully by Messrs. Aydon, Wise, and Field, and Figs. 191 and 192 show arrangements of boiler furnaces used by them.

FIG. 186.



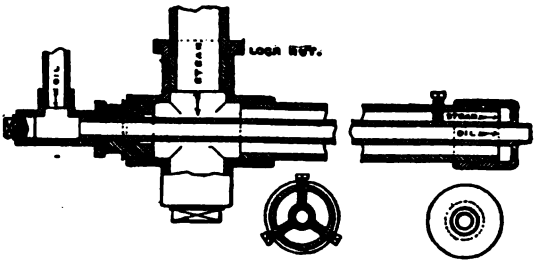
AYDON'S TYPE OF INJECTOR AS USED AT MESSRS FIELD'S.

FIG. 187.



AYDON'S TYPE OF INJECTOR AS USED AT WOOLWICH &c.

FIG. 188.



WISE, FIELD AND AYDON'S IMPROVED INJECTOR, AS USED AT MILLWALL.

FIG. 189

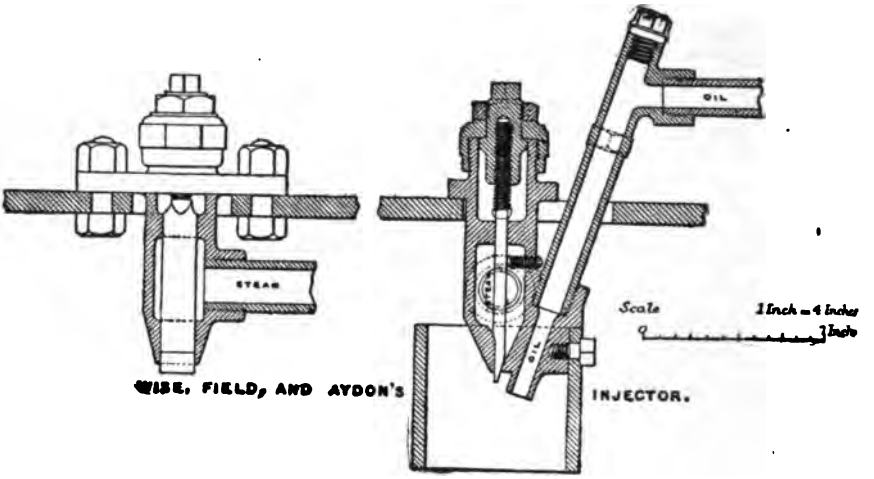


FIG. 190.

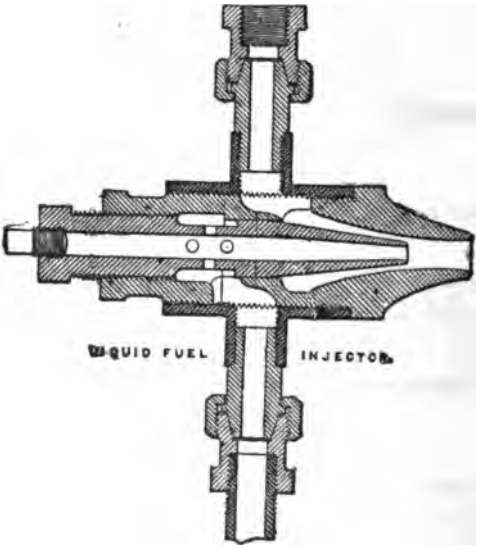
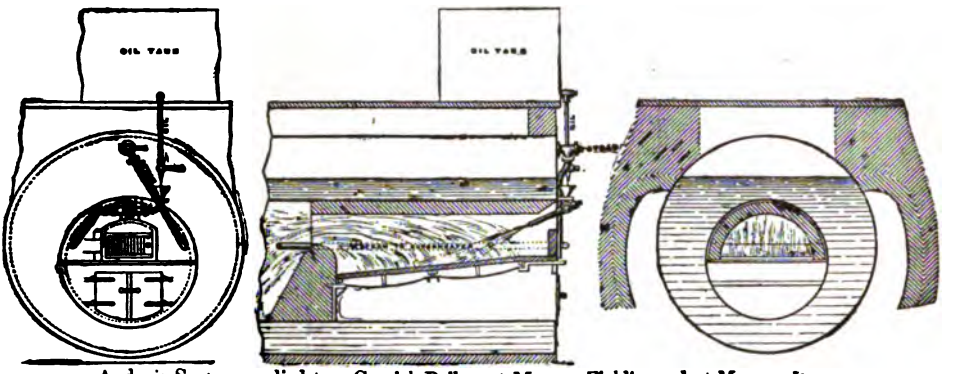
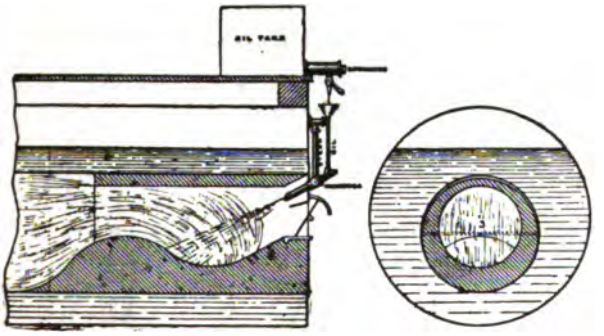


FIG. 191.



Aydon's System applied to a Cornish Boiler, at Messrs. Field's, and at Messrs. Barnes.

FIG. 192.

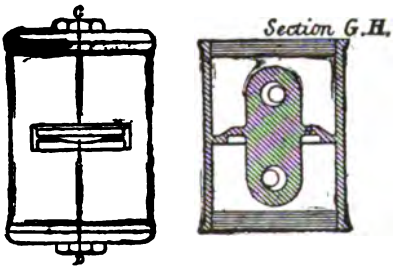


Aydon's type of Furnace, as used at Messrs. Barnes.

In the Russian oil field, various forms of apparatus have been employed, and of late years the use of the pulverizer or injector system in some shape has become almost universal.

In the steamers of the Caspian and Volga, the best known and most widely used* pulverizer is that of Lents, which is shown in Figs. 193–196.

FIG. 193.



* "Engineering," June 22, 1883; see also paper by Col. C. E. Stewart, "Proc. Roy. U.S. Inst.," June 18, 1886.

Fig. 194.

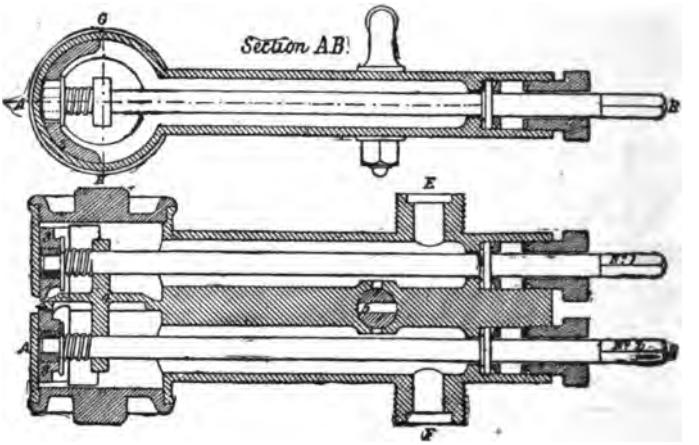


Fig. 195.

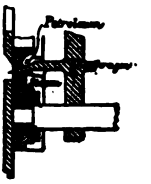
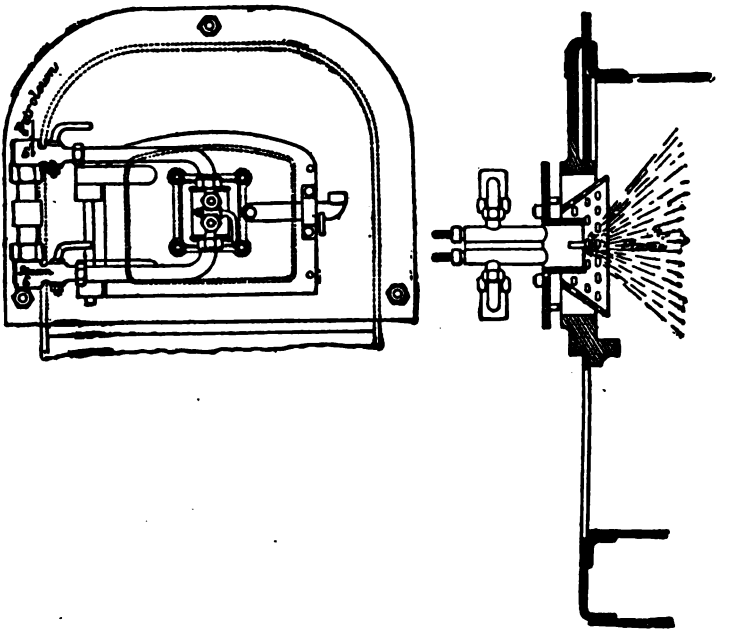


Fig. 196.

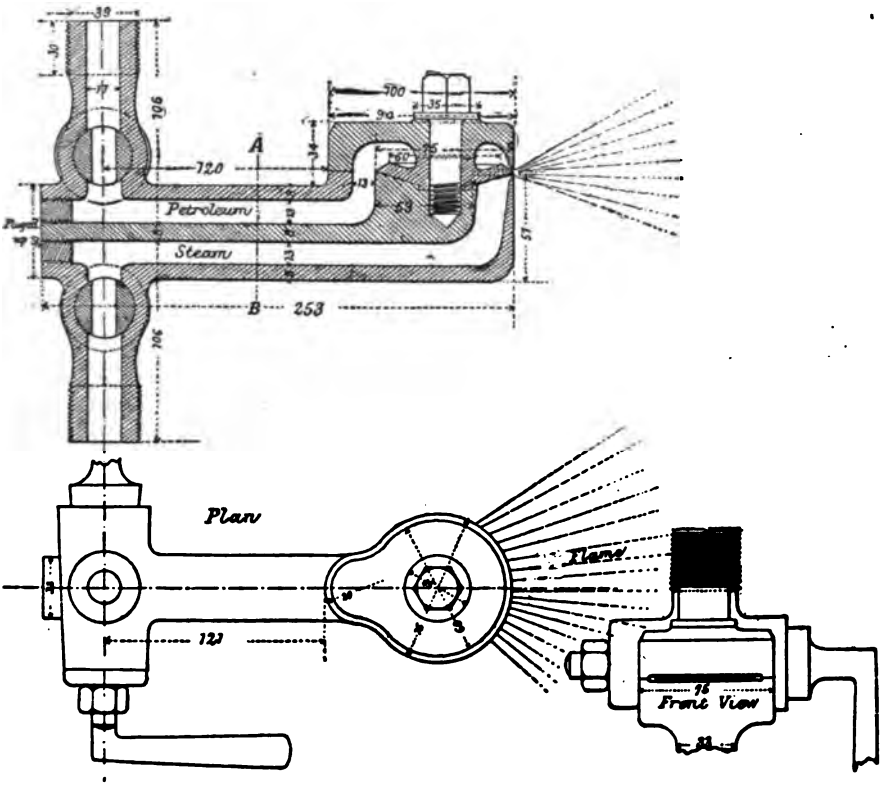


It consists of two horizontal iron pipes, to the upper of which petroleum is

fed, steam being admitted by the lower, each pipe having a cock for shutting off the supply. The two fluids enter the pulverizer at E and F (Fig. 194), but are prevented from mingling by the diaphragm (4). Notches are filed in the edge or lip of this diaphragm (Fig. 195), and through them the petroleum trickles, to be blown off by the steam, which escapes at the under side in jets, with intervening spaces for the admission of air. Two semicircular slides (3, 3) are used as regulators; these are kept to their working faces by helical springs, and are worked by eccentrics fixed at the ends of the spindles No. 1, No. 2.

On the locomotives of the Trans-Caucasian Railway, this apparatus did not succeed, as it blew the flame too directly on the tube plate, and, combustion not being complete, the tubes were fouled with soot. But in stationary boilers and on board ship, it is a favourite form of apparatus.

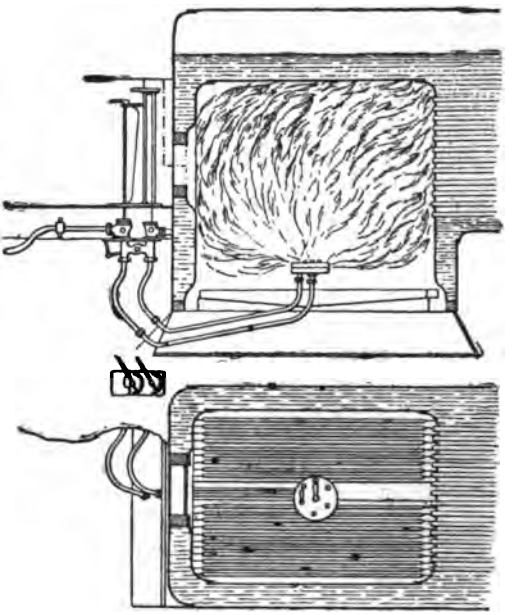
Fig. 197.



Artemeff's pulverizer, shown in Fig. 197, is a more simple arrangement, the difference being mainly in the means of regulation by cocks instead of slides, as in Lents'. The petroleum and steam enter by two passages, and meet round a portion of the diaphragm, where a slot is cut through the outer casing for the escape of the spray. The diaphragm itself is a conical washer, ground up to a close bearing with the lower and main part of the pulverizer, and held in its place by a cap and a single bolt. The apparatus is generally attached to the boiler by a swing joint, so that it can be turned back and taken to pieces rapidly, without interfering with the working of the boiler.

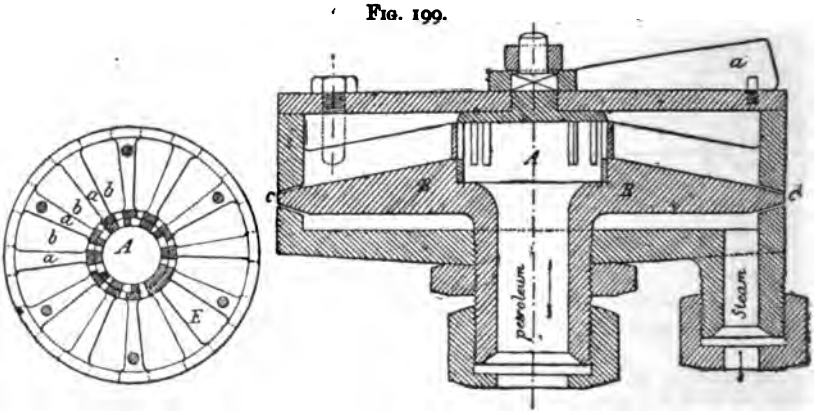
An ingenious central pulverizer for locomotives, invented by Brandt, is shown in Figs. 198 and 199. The petroleum enters through the central

Fig. 198.



pipe A, and, overflowing on to the diaphragm B, trickles down to the lip C, where it meets the steam and is driven off in spray. The steam and oil

Fig. 199.



are regulated by means of separate cocks, which are manipulated from the foot-plate, the burner being placed in the centre of the fire-box in locomotive boilers.

When applied to stationary boilers, another form of this pulverizer is used, which is illustrated in Figs. 200 and 201. This forms a conical flame, which has a helical or rolling motion when spiral grooves are cut in the conical head as proposed by Mr. Ludwig Nobel.

Karapetoff's apparatus, which is said to be an improvement upon the

other arrangements tried on the Russian railways, is shown in Figs. 202–204. It is fixed in the fire-box door in such a way as to throw a flat fan of flame

Fig. 200.

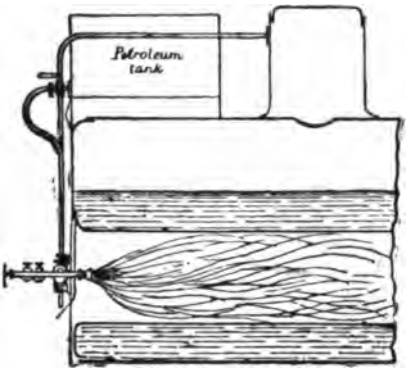


Fig. 201.

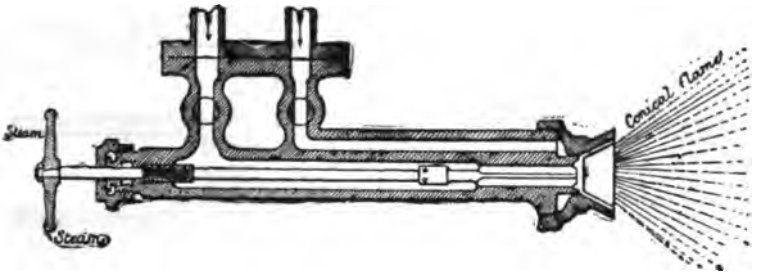
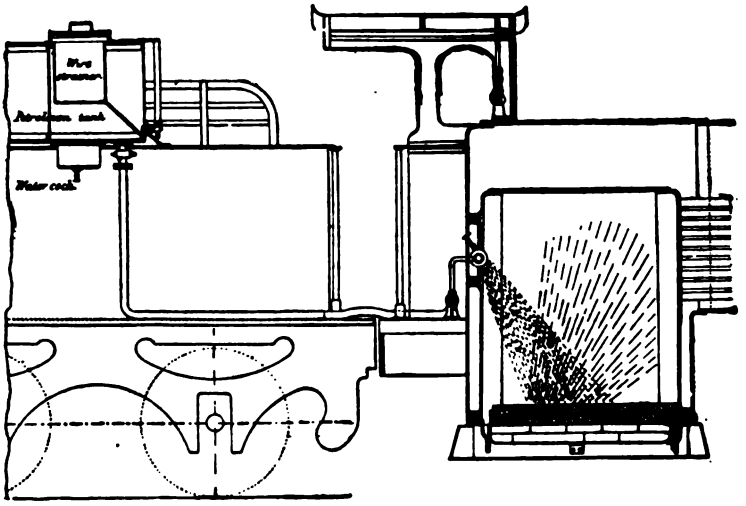
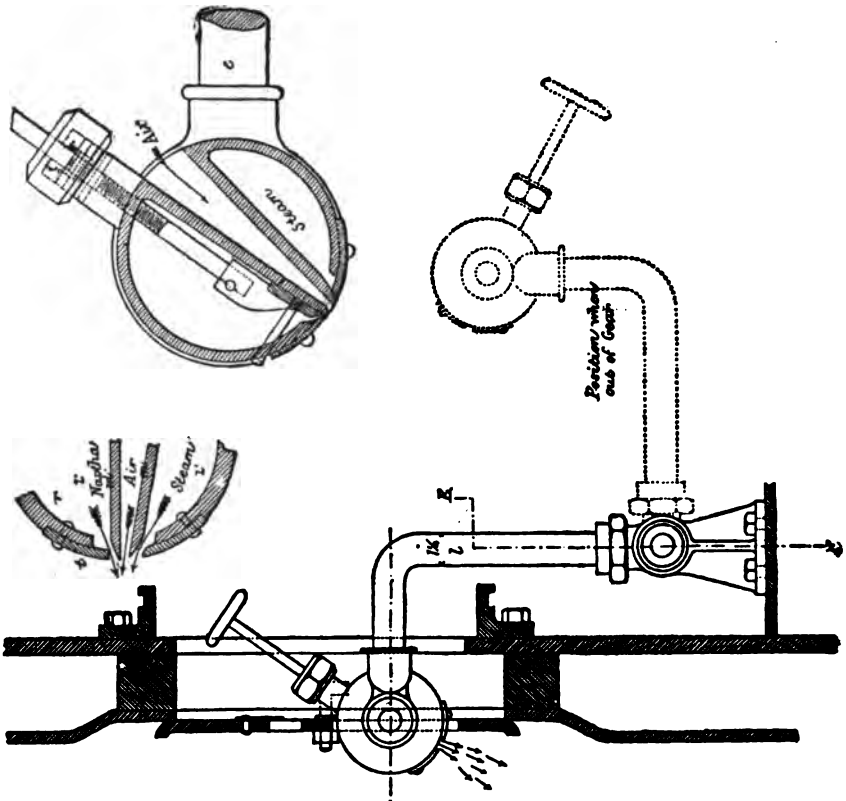


Fig. 202.



downwards on to a fire-brick bottom, which soon becomes very hot, and prevents the flame being extinguished, besides serving to ignite any particles of oil which fall upon it.

Fig 204


Air
Steam
Petroleum
Air
Steam
Position wheel
Fig 203
Sight hole
Air channel
Steam
Blow through cock
Petroleum

The burner is formed of a drum, having loose ends, and three channels cast in it, the upper for petroleum, the middle for air, and the lower for

FIG. 205.

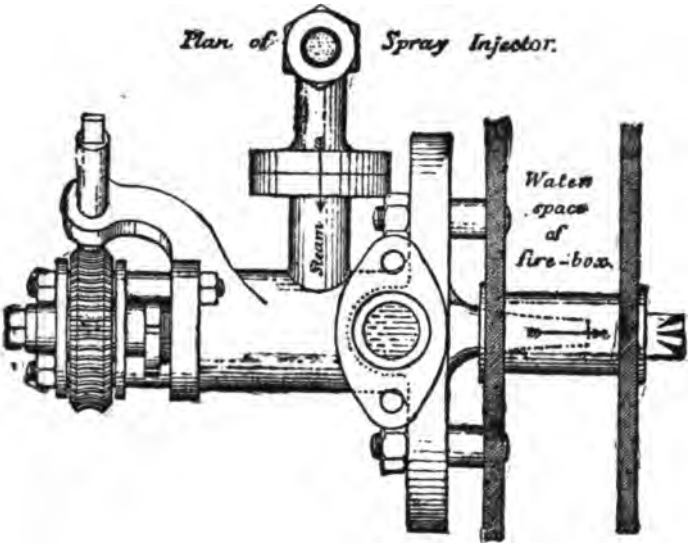
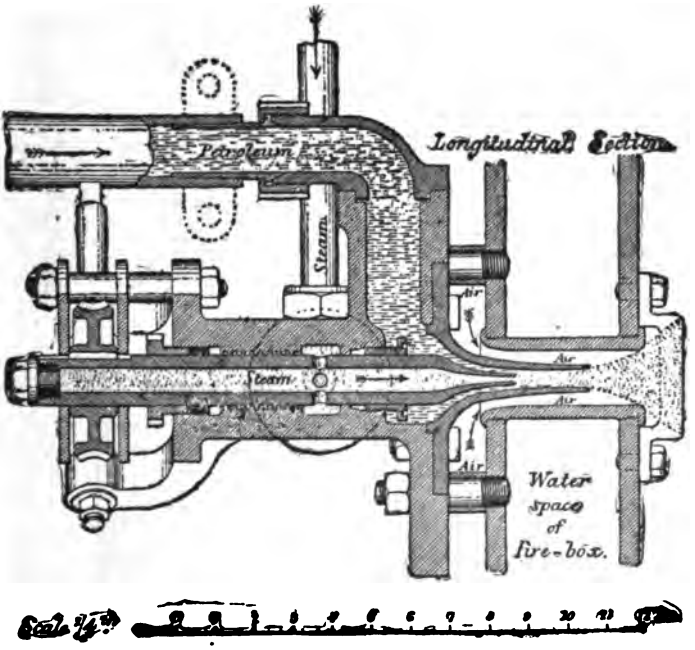


FIG. 206.



steam This method of admitting the air has proved very successful in preventing smoke.

After trials of other forms, the spray injector adopted by Mr. Thomas Urquhart* on the locomotives of the Grazi and Tsaritsin Railway is shown in Figs. 205 and 206. It is a development, with some useful added details, of the injector originally used by Aydon.

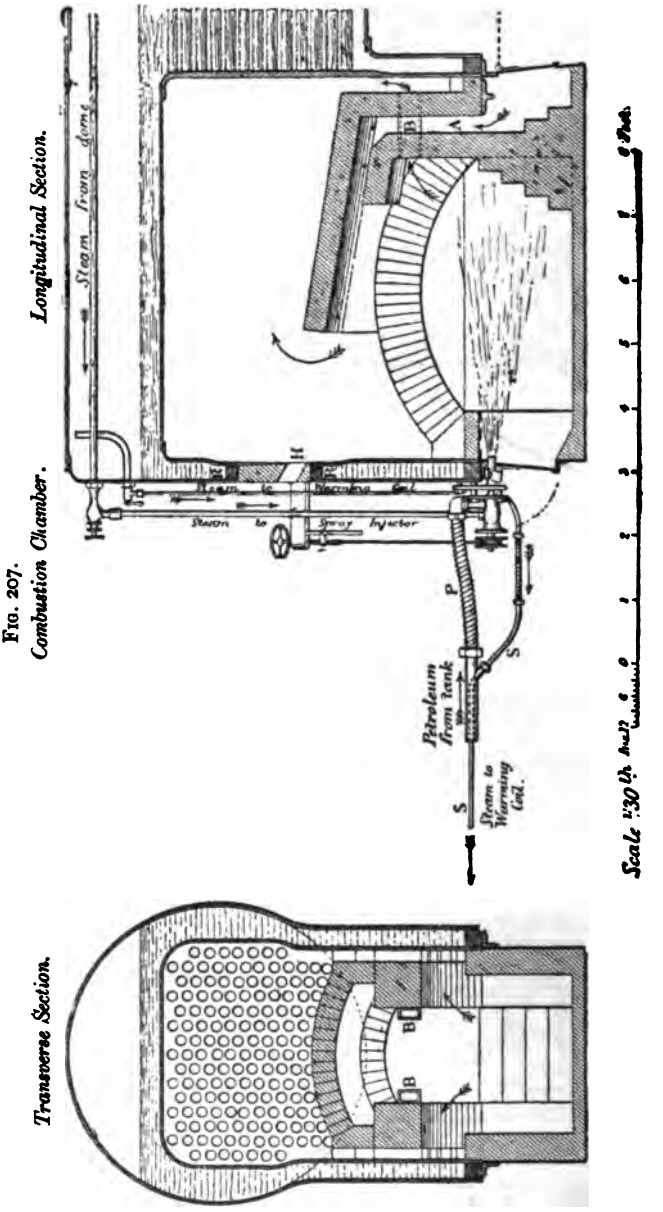


FIG. 207. Combustion Chamber.

The construction of furnaces ultimately adopted by Urquhart is also illustrated in Figs. 207–209, showing the radiating chamber of fire-brick which

* On the Use of Petroleum Refuse as Fuel in Locomotive Engines, "Proc. Inst. M.E.," 1884.

has been found to be necessary, and the means adopted to heat the air supply drawn in for combustion by the exhaust blast of the engine.

FIG. 208.

Locomotive Combustion Chambers.

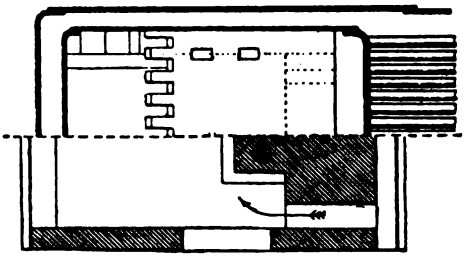
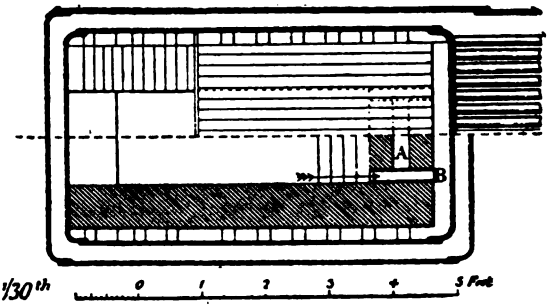


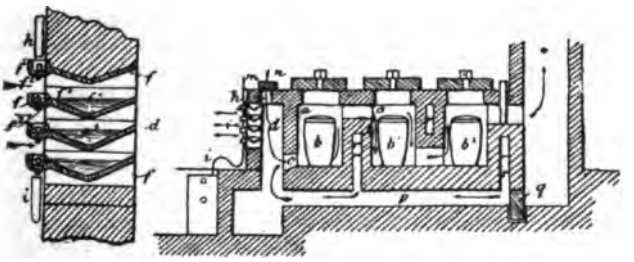
FIG. 209.



Mr. Urquhart shows* a construction of furnace which he proposes for Lancashire boilers when liquid fuel is used, but this does not possess the merits, just referred to, of the locomotive furnace.

Of other methods of using liquid fuel, a furnace for heating railway tyres is illustrated by Mr. Urquhart (*loc. cit.*, Plate 59). The oil is applied by a blast of air without steam or preliminary heating of the air, or any means for recovering waste heat.

FIG. 210. FIG. 211.



Aydon mentions† several furnaces which were used in this country, in Canada, and in the United States for various metallurgical operations, these

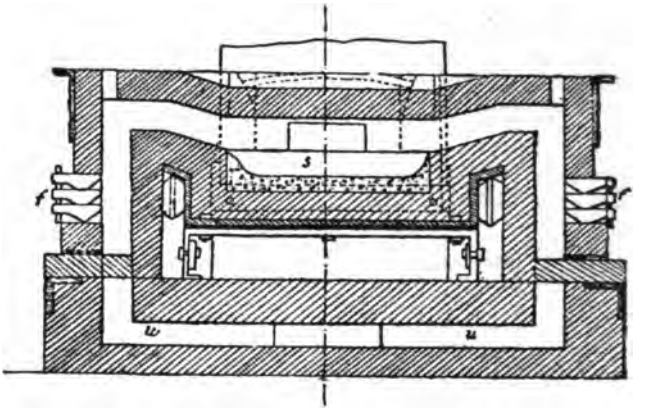
* "Proc. Inst. M.E.," 1884.

† On Liquid Fuels, "Min. Proc. Inst. C.E.," vol. lii. part ii. For accounts of the use of petroleum in iron-making, &c., see also "Jour. Iron and Steel Inst.," vols. i. 1882, pp. 248, 727; ii. 1882, p. 718; i. 1883, pp. 350, 360, 402; ii. 1883, p. 749; i. 1884, p. 319, &c. "Jour. Soc. Chem. Indus.," vol. i. pp. 123, 143.

having had the liquid fuel applied either by steam jets on Aydon's plan or in the form of gas on Dorsett's and Eames's plan.

The method of burning liquid fuel in open trays, which was invented by Mr. Carl Wittenström, and applied by him to his process for making wrought iron, or "mitis," castings, is described in the British Patent Specification of Mr. T. Nordenfelt, No. 11,543 of the year 1884.

FIG. 212.



Figs. 210 and 211 show this method as applied to a crucible furnace; *a*, Fig. 211, being the body of the furnace, *b*, b^1, b^2 the crucibles, and *c* the chimney. "The fire-box *d* has an aperture at the front, into which the fire-bars *f f* are built. They are iron troughs, placed one above the other, the number being varied at will. In Fig. 211 four are shown, the uppermost one not being used as a fire-bar, but only for feeding, and as a guide for the air. *h* is a pipe by which the naphtha or liquid fuel is supplied. It enters first into the pan f^1, and overflows from this pan by the short pipe f^2 into the pan f^1 of the fire-bar beneath. It then flows from this pan by the perforation f^3 into the main trough-like cavity f^4 of the bar, which it fills to the level of the mouth of the overflow f^3. The surplus liquid descends by this overflow to the pan f^1 of the bar below, and it fills the main cavity to the level of the overflow.

"The overflow from the lowest bar of the series is received into a pipe *i*, and is thereby led away into any suitable receptacle. The supply of liquid fuel should always be in excess of that which is consumed and evaporated upon the bars. Although the fuel is ignited where it lies in the cavities f^4 of the bars, nevertheless, in consequence of the limited supply of air between the bars (which, if necessary, may be controlled by a door), more air is required, and is admitted into the mixing chamber *d* through the aperture *m*, regulated by the slide *n*." To attain complete combustion and a high temperature, thorough mixture of the gases and air is effected by making them pass through narrow passages *o* before reaching the body of the furnace. *p* is a flue beneath the body of the furnace, through which the products of combustion may be passed direct to the chimney, while the body of the furnace is being opened for the removal of crucibles, or for other purposes. Suitable dampers *q* control this passage. For the purpose of cooling the partitions in the furnace, as well as for the saving of fuel, air is admitted through the channels *r* in the partitions and the flue *p* to the mixing chamber *d*.

Fig. 212 shows in vertical section an open-hearth steel furnace, having this method of using liquid fuel applied. Bars *f f* are provided on both sides of the furnace bed *s*, and the outlet to the chimney is through a chamber *t*, in

which materials are heated before being drawn on to the bed of the furnace for fusion. *u* is the direct passage to the chimney already described.

The application of this system to steam boilers is shown in Figs. 213–215. Fig. 213 is an end elevation, Fig. 214 a vertical section, and Fig. 215 a horizontal section of part of a boiler to show the combustion arrangements. *f f* are the trough-like bars; *h* is the pipe supplying the liquid fuel, and *i* is the pipe for escape of surplus fuel; *l* is the mixing chamber, and *m m* are passages by which air is admitted to this chamber. From this chamber, the gases and

FIG. 213.

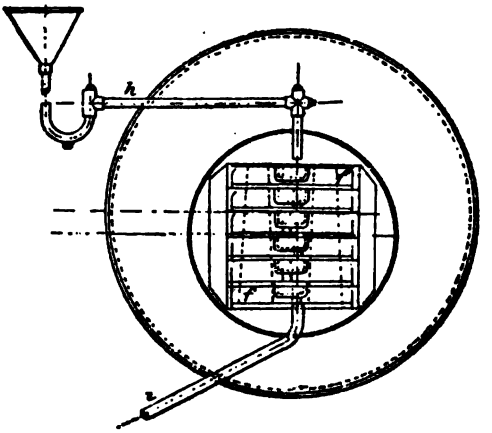


FIG. 214.

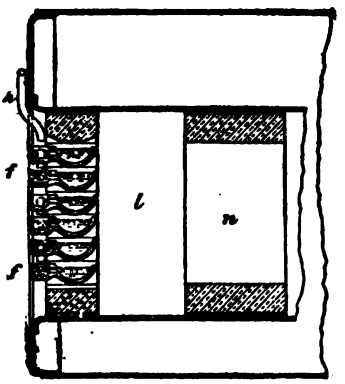
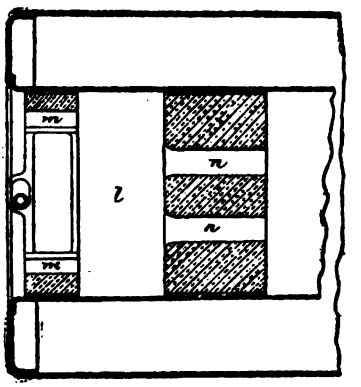


FIG. 215.

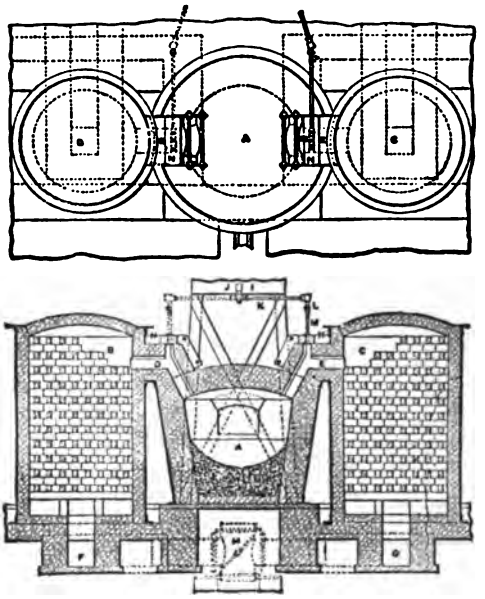


air pass through the narrow vertical passages *n*, and, being thus completely mixed, are then passed into the flue.

Fig. 216 shows a furnace designed by Mr. J. Riley, of Glasgow, to adapt regenerative furnaces to the supply of liquid fuel direct. The form of the furnace shown is that patented by Dick and Riley (No. 1,157—1883), in which the regenerator chambers are built above ground in separate iron casings, clear of the furnace body. The reverberatory chamber A is circular on plan; and two circular regenerative chambers B and C are built in connection with it on opposite sides. The upper parts of these regenerators communicate with A by passages D, E, and the lower parts communicate by F, G, with the flue, in which a reversing-valve H is arranged in the usual way. The whole heat of the waste gases is used for heating the incoming air, instead of

for heating regenerators for both air and gas. The liquid fuel is supplied to the furnace from a tank I placed a little higher than the furnace. The tank has a delivery-pipe J, having a stop-cock, and jointed to a pipe K, which may be moved horizontally on J as a pivot from side to side. It has also a second movable piece of pipe L joined to it. This last piece has several nozzles M, which enter holes made in fire-brick blocks N. These nozzles are so placed

FIG. 216.



as to project the oil into either D or E, according to the direction in which the heated air is at the time entering A. When the currents are reversed by the valve H, the nozzles are moved from one side of the furnace to the other.

A somewhat similar plan seems to have been carried out some years ago at the works of the Norway Steel and Iron Co., Boston, U.S.*

Results.—The record of results obtained by using liquid fuel is, as might be expected from the variety of plans used, one of great diversity.

The point aimed at in most of the trials has been the realization merely of a close approximation to the calorific values of the carbon and of the hydrogen *existing in the fuel*, as estimated by analysis. Too low an estimate, therefore, has been usually made of the value of the fuel, so that even moderate fluctuations in price have been allowed to interfere with its practical introduction more than once in its history; and there has not been recognized a sufficient stimulus to the improving and perfecting of methods of burning the fuel so that the best results should be obtained. Results which could not but be considered startling in the above view of the value of the fuel have been frequently obtained, but these have generally been received with incredulity, except where enthusiasm as to the subject has led to their being accepted, and to explanations of them being sought for. It has, however, only become possible to understand the matter fully since the facts as to oil-gas production have become known.

* See "Iron Age," Nov. 22, 1883; "Jour. Iron and Steel Inst.," vol. ii. 1883, p. 749.

1. There are no records of trials with Bridges-Adams' plan using compressed air, but the modern adaptation of this system by Mr. Percy Tarbutt is said to have yielded an evaporation (at 15 lbs. pressure of steam) of 15½ lbs. of water per lb. of oil, as against 8 to 9 lbs. with coal. In the s.s. *Himalaya*, of 100 h.p. nominal and 800 tons burthen, a consumption of 3½ tons of oil per day, as against 9 tons of coal per day, was, it is said, recorded on a voyage.

2. Richardson's plan was tested at Woolwich Dockyard under Mr. Trickett, the chief engineer, and gave evaporative results varying from 7.14 to 18.38 lbs. of water from 100° F. to steam at 212° F. per lb. oil —8 lbs. water per lb. of coal being the evaporative rate obtained with coal.

3. Simm and Barff's plan was tried in two steam vessels, and gave results showing 3 to 1 in favour of oil as compared with coal in one case, and an evaporative rate of about 12 lbs. of water per lb. of oil in the other. The apparatus as designed, however, did not stand the intense heat which was produced, and the retort was in each case melted.

In America much better results were obtained with Foote's apparatus. Experiments were made in June 1866 by Mr. Julius Adams on this system applied to a stationary boiler 6 feet in diameter by 13 feet 6 inches long, having an internal flue with return tubes. The mixture of steam and oil vapour was discharged into the furnace through ninety burners of $\frac{1}{16}$th inch in diameter. The flame was vivid, intense, and free from smoke, and 34 lbs. of water were evaporated from and at 212° F. per lb. of oil.

The performance in the trials on board the gunboat *Palos*, already referred to, in which the apparatus had 125 jet burners, is also said to have been good.

A new arrangement of the system of vaporization by an internally heated retort is announced by Mr. B. H. Thwaite,* of Liverpool, who thus describes his arrangement and its results :—

"The liquid hydrocarbon is injected by steam into the centre of a retort placed in the centre of the steam generator furnace; the steam and oil pass backwards and forwards through the retort, and become, on contact with its sides, converted into gas. The gas issues in an annular ring from the front end of the retort, and, striking against a diverting-plate of the air receiver, returns around the outside edge of the retort, and the gas is here met with an annular blast of air, producing a hollow cylinder of flame, in the inside of which is the retort encircled with flame from end to end. The outside periphery of the flame is in close contact with the perforated refractory lining of the flue, which not only becomes incandescent and prevents the oxidizing action of the flame on the plates, but prevents a too serious reduction in the temperature of the flame."

It was found necessary to have the pressure of steam above 50 lbs. per square inch, as below 30 lbs. per square inch it had a cooling effect on the retort.

The experiments, extending over two days, were carried out at the Hecla Engineering Works, Bamber Bridge, near Preston, in the furnace of a boiler of marine type, 5 feet 6 inches diameter by 8 feet 6 inches long; central flue 2 feet 8 inches diameter, with two cross Galloway tubes; forty return tubes of 2½ inches diameter. In the first day's experiments, the air for combustion was supplied by natural draught, and on the second day by forced draught from a Körting blower. The oil used was blast-furnace oil from Coatbridge, of which the following is the elementary analysis as made by Mr. A. H. Allen, of Sheffield :—

* "On Liquid Fuel, its Advantages for Firing Steam Generators" (London: Spon).

	1.		2.		Average.
Carbon	83.380	...	83.900	...	83.6400
Hydrogen	10.530	...	10.650	...	10.5900
Sulphur	0.087	...	0.088	...	0.0875
Oxygen (by difference)	6.003	...	5.872	...	5.9385
	100.000	...	100.000	...	100.2560

The proportion of phenoloïd bodies soluble in alkali was 16.5 per cent., leaving 83 per cent. of hydrocarbons. Sp. gr. 0.92.

The same quality of oil calorimetrically tested by Mr. W. Thompson gave the following results:—

Fahrenheit units of heat	16,080
Equivalent to lbs. of water from and at 212° F. converted into steam by 1 lb. of oil	16.66

The thermic value calculated from Mr. Allen's analyses with Favre and Silbermann's calorific co-efficients gives the oil as equal to 18,411, or 16 per cent. in excess of the actual calorimetric estimation.

In the first day's test, combustion was effected with 22 per cent. excess supply of air over that theoretically necessary to effect complete oxidation of the oxidizable elements of the oil. In the second day's experiment, as remarked, a forced draught was used, which caused a greater excess of air to be employed.

The following shows the efficiency calculated from the actual results, on the basis of the calorimetric value of 16.66 lbs. of water evaporated per lb. of liquid fuel from and at 212° F., along with Mr. Allen's analyses as a synthetical basis to arrive at the composition of the gas produced:—

Note.—Figures in brackets refer to lbs. of water evaporated from and at 212° F.

	First Day's Experiment.		Second Day's Experiment.	
Net actual evaporative efficiency	[14.97]	89.87 %	[14.21]	85.25 %
Net useful evaporative efficiency after deducting steam for aspirating oil	[14.33]	85.99 %	[13.58]	81.50 %
Net thermic efficiency, including the heat carried away by the products of combustion, and that necessary to elevate them up the chimney	[15.90]	95.42 %	[15.42]	92.60 %
Heating surface efficiency in lbs. of water evaporated per sq. ft. per hour	2.292		1.936	
Heat absorption efficiency tested by Carnot's law, where—				
Average initial temperature of combustion flue	1720° F.		1700° F.	
Average final chimney temperature	248° F.		262° F.	
Then	$\frac{1720-248\times100}{1720}=85.57$ %		$\frac{1700-262\times100}{1700}=84.53$ %	

A sample of astatki from Baku was obtained by Mr. Thwaite, and analysed for him by Mr. Allen in order to obtain a comparison of efficiency with the blast-furnace oil. The following are Mr. Allen's analyses:—

	1.		2.		Average.
Carbon	84 94	...	84.59	...	84 940
Hydrogen	13.91	...	14.05	...	13.960
Oxygen (by difference)	1.15	...	1.36	...	1.255
	100.00	...	100.00	...	100.155

Mr. W. Thompson's calorimetric test with this oil gave 18,611.2 British thermal units, equivalent to 19.28 lbs. of water from and at 212° F. converted into steam by 1 lb. of the oil.

The thermic value of the astatki calculated as before from the analyses gave the oil as equal to 20,927 F. units, or 11 per cent. in excess of the calorimeter test. The net useful evaporative efficiency of Baku astatki as compared with blast-furnace oil would, according to Mr. Thwaite's estimate, be therefore 16.58 lbs. of water from and at 212° F. per lb. of oil.

4. The method of steam-spray injection has been more largely used than any other, and there are consequently many results of its use on record.

One of the first trials with it was carried out on Aydon's plan at the works of Messrs. J. C. & J. Field at South Lambeth, in a small Cornish boiler 25 feet long, 5 feet 6 inches diameter, the furnace flue being 3 feet in diameter The quantity of water evaporated (the heating surface having been about 100 square feet) was 10 cubic feet per hour, or 20.8 lbs. of water per 1 lb. of oil. The result of several days' work showed an average of 19.5 lbs. of water evaporated per lb. of oil. This boiler, with the best Aberdare coal as fuel, evaporated only 6.5 lbs. of water per lb. of coal, showing an advantage of 3 to 1 in favour of liquid fuel.

In the following table of results, Nos. 1, 2, and 3 were obtained with a double-flued Galloway boiler 25 feet long, 6 feet in diameter, having a heating surface of 760 square feet, at chemical works at Hackney Wick; and Nos. 4, 5 and 6, with another double-flued Galloway boiler 25 feet long and 6 feet in diameter.

	1.	2.	3.	4.	5.	6.
					m.	m.
Duration of trial . . (hours)	68	—	236	5	1.57	1.10
Oil consumed in 24 hours (gallons)	250	240	230			
„ per hour . (lbs.)	104.1	100	95.8	16		
„ „ nominal h.p. (lbs.)	3.0	2.86	2.74			
Temperature of feed water (Fahr.)	50°	—	—	66°	46°	46°
Total quantity of water evaporated . . . (gallons)	11,050	—	51,456.25	1,524		
Ditto per hour . . (cub. ft.)	26.74	—	33.33			
Ditto ditto . . . (lbs.)	1,672	—	2,080			
Water evaporated per lb. of oil at steam pressure . . (lbs.)	16	—	21.71	19.05	8.69	12.06
Pressure of steam (lbs. per sq. in.)	35	—	35	28	40	42
Water evaporated per lb. of oil reduced for the temperature 212° F. by Rankine's formula .	19.4	20.30	26.0	22	10.37	14.4

In another instance, results were obtained during seven consecutive days' working, with a boiler of Cornish pattern, 30 feet long by 7 feet diameter, having a 3-feet flue, with combustion chamber arranged as in Fig. 192. Mr. Aydon says of this trial:—"The coal consumed under this boiler in doing equal duty amounted to 280 lbs. per hour. If it be supposed that the evaporation was 6 lbs. of water per lb. of coal, then 280 lbs. × 24 × 6 lbs. = 40,320 lbs. of water evaporated per 24 hours by 3 tons of coal. If the largest quantity given of the oil be taken—viz., 160 gallons—to do the same work in 24 hours, then 1,600 lbs. of oil will be expended every 24 hours. Now, 40,320 lbs. of water ÷ 1,600 lbs. of oil = 25.2 lbs. of water evaporated at 35 lbs. pressure per 1 lb. of oil at a temperature of 50° F., equivalent, when reduced for 212° F., to 28.9 lbs. of water per lb. of oil evaporated at atmospheric pressure. In this furnace much carbon was deposited, showing want of air. The ratio of efficiency in favour of liquid fuel is as 4.2 to 1. A low evaporative duty of the boiler with coal has been taken, but it is perhaps quite as much as the fuel, which was slack, could effect."

Other evaporative results obtained by this system as applied to marine boilers have been published, but the highest results are those which have been obtained by Admiral Selwyn and Mr. E. N. Henwood.

Admiral Selwyn announced that he witnessed at Messrs. Griffiths' factory, Victoria Park, London, in a Cornish boiler having a fire-brick combustion chamber built inside the flue, "160 gallons of oil per day doing the work of 3 tons of coal, or an evaporative effect of 46 lbs. of water per lb. of fuel."

This result was confirmed by continuous work with a similar boiler during the year 1884, when, using cold feed-water, Admiral Selwyn obtained the following results:—

Date.			Lbs. of Water evaporated per lb. of Oil.
1884.	Aug. 15	...	46
	„ 28	...	29
	Sept. 2	...	24
	„ 12	...	33
	„ 17	...	23
	„ 18	...	29
	„ „	...	33
	„ 19	...	37
	„ 22	...	29
	Oct. 9	...	35
	„ „	...	46

These results were constantly repeated during a long period of working with an ordinary 40 h.p. marine boiler having 32 square feet of grate surface.

The following analyses of the waste gases escaping from this boiler show that combustion was nearly perfect, and that little or no excess of air was being admitted to the furnace:—

ANALYSES OF WASTE GASES FROM BOILER FURNACE.

CO_2	14.19	...	13.12	...	18.08
CO	5.20	...	8.20	...	0.34
Free oxygen	0.78	...	0.48	...	0.34
Hydrocarbons	1.30	...	not determined	....	none
H, marsh gas, &c.	not known	...	10.18	...	none
Nitrogen	78.53	...	68.00	...	81.24
	100.00	...	99.98	...	100.00

Mr. E. N. Henwood, following on Admiral Selwyn's lines, has obtained similar results in the boilers of the s.s. *Ryde*, of 120 tons and about 100 h.p.

Trials were recorded in "Iron" of March 26, 1886, which gave an evaporative effect of 41 lbs. of water per lb. of oil, or a consumption of from .69 to .75 lb. of fuel per indicated h.p. per hour. In May of the same year, 30 lbs. of water were evaporated per lb. of oil when the engines were indicating 78 h.p., showing a consumption of .7 lb. per indicated h.p. per hour.

The results obtained by Mr. Urquhart in locomotives are too important to be passed over. In August 1884, he had under his care over 100 locomotives of different types consuming liquid fuel, and his results of working are carefully classified in the following tables.

Comparing naphtha refuse (Russian) and anthracite, Mr. Urquhart says that "the former has a theoretical evaporative power of 16.2 lbs. of water per lb. of fuel, and the latter of 12.2 lbs. at an effective pressure of 8 atmospheres, or 120 lbs. per square inch; hence, petroleum has, weight for weight, 33 per cent. higher evaporative value than anthracite. Now, in locomotive practice, a mean evaporation of from 7 to 7½ lbs. of water per lb. of anthracite is about what is generally obtained, thus giving about 60 per cent. of efficiency, while 40 per cent. of the heating power is unavoidably lost. But

with petroleum, an evaporation of 12.25 lbs. is practically obtained, giving $\frac{12.25}{16.2} = 75$ per cent. efficiency. Thus, in the first place, petroleum is theoretically 33 per cent. superior to anthracite in evaporative power; and, secondly, its useful effect is 15 per cent. greater, being 75 per cent. instead of 60 per cent.; while, thirdly, weight for weight, the practical evaporative value of petroleum must be reckoned as at least from $\frac{12.25 - 7.50}{7.50} = 63$ per cent. to $\frac{12.25 - 7.00}{7.00} = 75$ per cent. higher than that of anthracite."

TABLE I.—GRAZI AND TSARITSIN RAILWAY.

Expenditure of Coal in 1882 *and Petroleum Residuum in* 1885, *inclusive of Kindling Wood, on two Types of Engines.*

EIGHT-WHEELED ENGINES.

With Coal in 1882.

Month.	Average Number of Cars in Train.	Aggregate Distance run by Locomotives.	Aggregate Distance of Unproductive Run of Locomotives.	Aggregate Distance run by Freight Cars.	Average Consumption of Fuel and Cost per Mile.	
					Coals.	Cost.
		miles.	miles.	miles.	lbs	*d.*
January . .	33.82	41,296	7,003	1,294,696	98.83	14.76
February . .	34.21	37,444	5,770	1,082,924	86.91	12.66
March . . .	33.41	20,881	1,956	632,410	87.44	12.99
April . . .	38.14	24,293	3,329	850,147	73.01	10.60
May . . .	41.24	31,145	4,757	1,170,956	70.62	10.36
June . . .	40.53	37,520	4,907	1,321,835	73.04	10.73
July . . .	43.64	29,749	5,802	1,045,201	71.74	10.55
August . .	39.99	38,751	6,028	1,308,734	71.28	10.01
September . .	39.54	56,586	9,298	1,866,171	76.26	10.75
October . .	35.13	71,041	11,891	2,081,474	77.06	11.04
November . .	36.56	70,466	12,648	2,114,172	92.54	13.49
December . .	34.00	52,763	7,166	1,416,010	99.82	14.42
Total and average for year . .	37.51	511,935	80,555	16,184,730	81.43	11.50

With Petroleum Residuum in 1885.

Month.	Average Number of Cars in Train.	Aggregate Distance run by Locomotives.	Aggregate Distance of Unproductive Run of Locomotives.	Aggregate Distance run by Freight Cars.	Average Consumption of Fuel and Cost per Mile.	
					Petroleum Residuum.	Cost.
		miles.	miles.	miles.	lbs.	*d.*
January . .	37.72	83,636	16,066	2,549,230	48.30	6.71
February . .	37.15	55,222	10,449	1,663,813	49.98	5.36
March . . .	30.95	38,742	3,247	1,405,162	52.79	8.82
April . . .	41.03	60,477	9,809	2,079,544	42.68	6.95
May . . .	40.81	87,805	13,489	3,033,003	41.00	6.32
June . . .	41.68	75,175	11,029	2,673,988	41.84	5.47
July . . .	38.80	63,901	8,160	2,120,526	38.19	5.46
August . .	40.32	74,272	10,796	2,560,034	41.50	6.02
September . .	39.76	82,415	13,241	2,654,637	41.22	5.88
October . .	37.61	101,253	15,468	3,226,698	47.74	6.77
November . .	36.24	82,346	16,434	2,388,761	42.95	7.48
December . .	34.85	63,468	9,482	1,881,136	54.19	8.60
Total and average for year . .	38.08	868,712	137,670	28,565,555	45.83	6.50

TABLE I.—(*continued*).

SIX-WHEELED ENGINES.

With Coal in 1882.

Month.	Average Number of Cars in Train.	Aggregate Distance run by Locomotives.	Aggregate Distance of Unproductive Run of Locomotives.	Aggregate Distance run by Freight Cars.	Average Consumption of Fuel and Cost per Mile.	
					Coals.	Cost.
		miles.	miles.	miles.	lbs.	*d.*
January . .	21.32	78,244	36,032	897,826	62.60	9.35
February . .	27.47	43,160	23,008	560,152	55.15	9.90
March . . .	26.52	27,742	15,337	329,249	52.73	7.66
April . . .	28.59	57,514	22,497	1,004,129	53.84	7.78
May . . .	31.90	111 181	40,974	2,241,273	56.58	8.08
June . . .	30.74	147,720	48,638	3,043,384	57.46	8.46
July . . .	28.39	145,232	51,826	2,652,482	48.69	7.13
August . .	27.04	152,659	52,697	2,703,475	49.88	6.92
September . .	28.93	143,000	50,112	2,693,239	55.49	7.71
October . .	23.30	163,442	53,837	3,101,778	62.29	8.26
November . .	21.60	159,669	43,640	2,508,388	63.88	9.15
December . .	20.04	112,118	36,081	1,517,773	68.37	9.72
Total and average for year . .	26.32	1,341,681	474,679	23,253,148	57.25	7.80

With Petroleum Residuum in 1885.

Month.	Average Number of Cars in Train.	Aggregate Distance run by Locomotives.	Aggregate Distance of Unproductive Run of Locomotives.	Aggregate Distance run by Freight Cars.	Average Consumption of Fuel and Cost per Mile.	
					Petroleum Residuum.	Cost.
		miles.	miles.	miles.	lbs.	*d.*
January . .	22.14	114,192	46,052	1,509,005	34.43	4.77
February . .	22 01	89,648	37,513	1,148,056	34.09	4 84
March . . .	22.58	88,950	33,721	1,097,442	28.98	4 82
April . . .	25.33	141,584	46.654	2,354,348	31.73	5.16
May . . .	28.49	179,872	65,985	3,246,003	29.88	4.59
June . . .	28.35	144,669	55,347	2,533,104	29.93	4.28
July . . .	24.77	131.341	48,001	2,064,742	27.57	3.71
August . .	28.27	128,559	46,677	2,315,544	28.75	4.17
September . .	31.89	130,846	46,088	2,703,087	32.07	4.55
October . .	28.04	125,523	38,266	2,448,912	35.55	5.09
November . .	21.41	119,788	36,258	2,451,573	35.74	5.21
December . .	22.15	92,361	34,171	1,287,893	38.13	5.74
Total and average for year . .	25.45	1,487,333	534,733	25,159,709	32.23	4.50

TABLE II.—PETROLEUM REFUSE.

Continuous Trials in Seventeen Trips on different sections of Grazi and Tsaritsin Railway, to ascertain Mean Consumption in Winter-time.

Date. 1883.	Section of Line.	Locomotives.	Train.	Train alone. Number of Loaded Cars.	Train alone. Gross Load.	Distance Run. Versts.	Distance Run. Miles.	Car-miles.	Petroleum Refuse consumed, including Lighting up.	Atmospheric Temperature. Réaum.	Atmospheric Temperature. Fahr.	Weather.
				No.	Tons.				Tons.	°	°	
Jan. 18	Borisoglebsk to Burnack, and back	23	24–23	24	384	144	95	2,280	1.739	− 15	− 2	Side wind.
19	Ditto, ditto	23	28–25	24.33	389.3	144	95	2,303	1.854	− 8 to − 10	14 to 9½	Strong side wind.
21	Borisoglebsk to Filonoff	23	29	26	416	104	69	1,794	1.116	− 5	21	Calm.
22	Filonoff to Archeda	23	21	23.4	374.4	118	78	1,825	1.4401	− 7	16	Light side wind.
23–4	Archeda to Tsaritsin, and back	23	27–32	24	384	292	193	4,632	3.581	− 17 to − 18	− 6 to − 8½	Strong side wind.
Feb. 13	Archeda to Tsaritsin	8	27	14	224	146	97	1,358	1.326	− 4	23	Light wind.
15	Borisoglebsk to Tsaritsin	7	27–31	22	352	368	254	5,588	4.653	− 6	18½	Light side wind.
23	Ditto	35	27–31	22	352	368	254	5,588	4.657	− 10 to − 15	9½ to − 2	Strong side wind.
March 8	Archeda to Tsaritsin	8	21	14	224	146	97	1,358	1.394	+ 2	36½	Calm.
11	Tsaritsin to Archeda, and back	14	26–31	24.43	390.9	292	193	4,698	3.2205	− 7	16	Side wind.
14	Archeda to Ilovla	40	30	21	346	58	38	798	0.5901	− 11	7	Calm.
	Means and Totals			21.74	357.8	2,180	1,463	32,223	25.5707			

Mean Consumption of Petroleum Refuse = 39.15 lbs. per train-mile, including lighting up.
Mean cost of Petroleum Refuse, at 21*s.* per ton, = 4.4 pence per train-mile.

Equivalent Russian and English Measures.

sajene = 7 feet. 500 sajenes = 1 verst = 0.6629 mile.
1 pound = 0.90285 lb. 40 pounds = 1 pood = 36.114 lbs. 1 ton = 62.0257 poods.
1 copeck = 0.24 penny. 100 copecks = 1 rouble = 24 pence.

TABLE III.—PETROLEUM REFUSE.

Comparative Trials with Petroleum, Anthracite, Bituminous Coal, and Wood, between Archeda and Tsaritsin on Grazi and Tsaritsin Railway, in Winter Time.

Date. 1883.	Locomotive.	Train.	Train alone. Number of Loaded Cars.	Train alone. Gross Load.	Distance run.	Car-miles.	Fuel.	Consumption, including lighting up. Total.	Consumption, including lighting up. Per Train-mile.	Cost of Fuel per Train-mile.	Atmospheric Temperature and Weather.
			No.	Tons.	Miles.					Pence.	
Feb. 8	8	32-23 / 32-23	25	400	388	9,700	Anthracite . .	31,779 lbs.	81.90 lbs.	11.957	−17° to −18° Réau. equivalent to −6° to −8½° Fahr.
	14	24-21 / 24-21	25	400	388	9,700	Bituminous coal .	37,557·5 „	96.53 „	14.093	
	7	26-29	25	400	194	4,850	*Petroleum refuse* .	9,462 „	48.77 „	5.487	Strong side wind.
March 6	24	32-23	25	400	194	4,850	Anthracite . .	12,639.5 „	65.15 „	9.512	−5° to −9° Réau. equivalent to 21° to 12° Fahr.
	21	24-21	25	400	194	4.850	Wood, in billets .	1,071.8 cub. ft.	5.52 c. ft.	8.5	
	23	26-27	25	400	194	4,850	*Petro'eum refuse* .	7,223 lbs.	37.23 lbs.	4.188	Light side wind.

Prices of Fuel.—Petroleum refuse, 21*s.* per ton. Anthracite and bituminous coal, 27*s.* 3*d.* per ton.
Wood, in billets, 42*s.* per cubic sajene = 343 cubic feet; equivalent to 1.47 penny per cubic foot.

Dimensions of Locomotives.—Cylinders, 18½ ins. diam. and 24 ins. stroke. Wheels, 4 ft. 3 ins. diam. Total heating surface, 1,248 sq. ft.
Total adhesion weight, 36 tons. Boiler pressure, 8 to 9 atm.

TABLE IV.—PETROLEUM REFUSE.

Continuous Trials in Nineteen Trips between Archeda and Tsaritsin on Grazi and Tsaritsin Railway, to ascertain Mean Consumption in Summer Time.

Date 1883. June.	Locomotive.	Train.	Number of Loaded Cars. From Tsaritsin to Gorodisha (14 Miles).	From Gorodisha to Archeda (83 Miles).	From Archeda to Tsaritsin (97 Miles).	Mean for Total Distance.	Distance run.	Petroleum Refuse consumed, including lighting up.	Mean Results, including lighting up.
			No.	No.	No.	No.	Miles.	Ton.	
8	15	38	25	30	—	29	97	1.715	Mean consumption of petroleum refuse, 32.08 lbs. per train-mile.
,,	29	28	25	30	—	29	97	1.847	
9	15	25	—	—	30	30	97	1.219	
,,	29	27	—	—	30	30	97	1.128	
,,	57	30	25	30	—	29	97	1.704	
,,	23	32	25	30	—	30	97	1.456	Mean cost of petroleum refuse, at 21*s.* per ton, 3.61 pence per train-mile.
10	15	38–25	25	30	30	29	199	2.957	
11	29	31	—	—	31	31	97	1.256	
,,	23	21	—	—	30	30	97	1.149	
10	29	30	25	30	—	29	97	1.453	
11	23	12–21	25	30	—	29½	194	2.701	
12	29	26–27	25	30	30	29½	194	2.828	Mean evaporation, 11.35 lbs. of water per lb. of petroleum refuse.
17	57	34	12	30	—	27½	97	1.419	
21	14	36	10	30	—	27	97	1 399	
22	14	11	—	—	30	30	97	1.138	
,,	57	21	—	—	30	30	97	1.102	
Mean and Totals						29.3	1,848	26.471	

TABLE V.—PETROLEUM REFUSE.

Comparative Trials with Petroleum, Anthracite, and Bituminous Coal, between Archeda and Tsaritsin on Grazi and Tsaritsin Railway, in Summer Time.

Date. 1883. July.	Locomotive.	Train.	Train alone. Number of Loaded Cars.	Train alone. Gross Load.	Train-miles.	Fuel.	Consumption, including lighting up. Total.	Consumption, including lighting up. Per Train-mile.	Cost of Fuel per Train-mile.
			No.	Tons.			lbs.	lbs.	Pence.
13	37	—	30	480	194	Bituminous coal	14,084.07	72.598	10.599
	14	—	30	480	194	*Petroleum refuse*	6,175.325	31.831	3.581
25	32	31–34	30	480	194	Anthracite . .	12,784.002	65.897	9.621
	57	27–12	30	480	194	*Petroleum refuse*	6,103.097	31.459	3 539

Prices of Fuel.—Petroleum refuse, 21*s.* per ton; anthracite, and bituminous coal, 27*s.* 3*d.* per ton.

Comparative Monthly Averages during 1883 with Coal and Petroleum Refuse in Locomotives working Main-line Trains on Grazi and Tsaritsin Railway.

TABLE VI.—CONSUMPTION OF FUEL PER TRAIN-MILE.

Locomotives.	Trains.	Fuel.	Monthly Averages of Consumption per Train-mile.												Mean.
			Jan.	Feb.	Mar.	April.	May.	June.	July.	Aug.	Sept.	Oct.	Nov.	Dec.	
			lbs.	lbs.	lbs.	lbs.	lbs.	lbs.	lbs.	lbs.	lbs.	lbs.	lbs.	lbs.	lbs.
Eight wheels coupled	Goods	Coal *	98.06	108.96	100.79	76.27	76.27	79.00	74.91	73.55	79.00	85.81	98.06	95.34	87.17
Six wheels coupled	Goods	Coal *	73.55	77.63	70.82	64.01	55.84	61.29	54.48	55.84	65.38	80.36	92.62	85.81	69.80
		Petroleum refuse	**53·12**	**54·48**	**46·31**	**42·22**	**34·05**	**35·41**	**31·33**	**36·10**	**40·86**	**39·50**	**50·39**	**54·48**	**43·19**
Four wheels coupled	Mixed	Coal *	51.76	76.27	43.58	34.05	36.77	35.41	42·22	49.03	51.76	40.86	49.03	58.57	47.44
Four wheels coupled	Passenger	Coal *	40.80	49.03	46.31	36.77	34.05	32.69	31.33	32.69	36.77	39.50	42.22	50.39	39.38
		Petroleum refuse	—	—	—	—	—	—	—	—	**20·43**	**31·33**	**32·69**	**34·05**	**29·62**

TABLE VII—COST OF FUEL PER TRAIN-MILE.

Locomotives.	Trains.	Fuel.	Monthly Averages of Cost per Train-mile.												Mean.
			Jan.	Feb.	Mar.	April.	May.	June.	July.	Aug.	Sept.	Oct.	Nov.	Dec.	
			Pence.	Pence.	Pence.	Pence.	Pence.	Pence.	Pence.	Pence.	Pence.	Pence.	Pence.	Pence.	Pence.
Eight wheels coupled	Goods	Coal *	13.495	15.635	14.346	11.226	11.319	11.704	11.186	10.925	11.552	12.471	14.600	13.930	12.699
Six wheels coupled	Goods	Coal *	10.520	11.099	9.897	9.405	8.387	9.317	8.217	8.279	9.694	11.776	13.647	12.344	10.212
		Petroleum refuse	**7·294**	**7·602**	**6·158**	**4·973**	**4·040**	**4·163**	**3·617**	**4·170**	**4·948**	**4·771**	**6·817**	**7·356**	**5·495**
Four wheels coupled	Mixed	Coal *	7.353	10.973	6.672	4.934	5.466	4.988	6.267	7.269	11.215	5.908	7.102	8.652	6.932
Four wheels coupled	Passenger	Coal *	6.070	7.023	6.602	5.144	4.829	4.670	4.445	4.819	5.165	5·633	6.111	7.580	5.672
		Petroleum refuse	—	—	—	—	—	—	—	—	**2·411**	**5·611**	**4·366**	**4·634**	**3·808**

* Of the coal consumed, 49 per cent. was anthracite and 51 per cent. was bituminous coal.
The anthracite used is from a top seam not very pure, and is called a semi-anthracite.

Mean Prices of Fuel.—Petroleum refuse, 23*s.* 4*d.* per ton; coal, 27*s.* per ton.

5. Results obtained with the system of a primary gasification of the oil in a separate chamber or retort have already been referred to (under section 3), the retort having been in these cases heated by the furnace in which combustion of the resulting oil-vapour took place.

Dorsett's plan of an external gasifying chamber was introduced in 1868 at his chemical works at Deptford, and gave results of great economy. Trials were also carried out in the steamer *Retriever* of 500 tons burthen and about 90 nominal h.p., and the ratio of evaporative duty was as 2.5 to 2.7, is to 1 in favour of liquid fuel as compared with coal.

Furnaces at Woolwich Dockyard and at Millwall were also fitted up on this system for heating boiler plates, and for shingling or balling scrap iron, and gave a ratio of 2.87 to 1 in favour of the quantity of liquid fuel used, and a saving in time of heating as 2.5 to 1 in favour of oil. The relative duty in the scrap furnace was as 1.5, is to 1 in favour of oil.

Eames's plan (as shown in Fig. 184), as applied to a furnace for welding piles of scrap having a steam boiler heated by the waste heat, and also as applied in another case to a puddling furnace, was very successful, the duty of the scrap furnace being stated at from 7 to 8 times in favour of liquid fuel as compared with coal, and that of the puddling furnace as 12 to 1 in favour of liquid fuel.

A similar system was (under the name of vapour fuel) introduced* on an extensive scale at the works of the Norway Steel and Iron Company, Boston, U.S.A., and applied to steam-raising, puddling, re-heating, and steel-melting furnaces—the latter being a 10-ton open-hearth furnace. Crude petroleum was stored in tanks, and led from them by pipes to the vapour generators,† called "thermogens," in the different parts of the works. A thermogen seems to have been connected with each furnace worked with liquid fuel, but the regenerative furnaces required merely the air for combustion to be heated in the regenerators.

All the operations mentioned were carried out successfully with this fuel, and were found to be more entirely under control than when coal or producer gas was used. A considerable saving in first cost, repairs, and cost of fuel is announced, and also a larger output, from furnaces worked on this plan.

Archer's oil-gas generator (Fig. 185) has also been used in connection with steel-melting furnaces at the works of the Steel Company of Scotland, Limited, and gave good results as to the economy of fuel, although it is questionable whether the form of this apparatus is the most suitable for continued use.

The wide variety in, or the intermittent character of, the results obtained by the different methods of using liquid fuel—and even by the same method under different circumstances—is due to imperfections in the apparatus used, and to want of experience in the best method of treating the fuel.

Admiral Selwyn explained the high evaporative rates obtained by him, by assuming that the hydrogen of the steam used in his injectors is burned; and Mr. Henwood, following in his steps, has claimed for his apparatus that the oil and steam are so proportioned that the hydrogen is fully utilized in the same way in his furnaces. But, inasmuch as, in the dissociation of the hydrogen and oxygen composing steam, an amount of heat is absorbed and becomes latent, which is the same as that developed when the hydrogen is burnt and again combines with oxygen to form water, it is very improbable that this view affords an explanation of the results obtained. On the other hand, those who have rejected Admiral Selwyn's view have

* "Iron Age," Nov. 22, 1883; "Jour. Iron and Steel Inst.," vol. ii. 1883, p. 749; &c.
† See "Iron," vol. xxiv. p. 54.

not given proper weight to several considerations which belong to thi subject.

The estimates made of the calorific value of liquid fuels from their elementary chemical analyses are usually based upon the amount of carbon contained in them *as if it were solid carbon*, and *to be burned as such*. It is, however, beginning to be understood that, even in estimating the calorific power of coal, some alteration is required in this respect, because part of the carbon in it (probably all) does not exist as such in the solid state. In liquid fuels, it is certain that none of it exists in that state, and hence weight must be allowed to the argument advanced years ago by Aydon. Speaking of liquid fuel, he said: "Here was a fuel naturally prepared the first stage towards gasification, as to effect the same result artificially 6,000 or more heat units would have to be expended, which heat would become latent, and so be lost as useful work. Now, these 6,000 heat units added to 15,000 heat units derived from converting or burning carbon into carbonic acid would give 21,000 heat units, which the late Prof. Rankine stated to be the amount due to gaseous carbon." Aydon then applied this estimate to the case of American petroleum, and to the creosote or dead oil which he had used at Woolwich. Taking petroleum of the composition, carbon 86, hydrogen 14, if the value for gaseous carbon were employed, it would give this a calorific value of 26.887 lbs. of water per lb. of oil. The dead oil as analysed by Prof. Church, contained—

Carbon	86.48
Hydrogen	7.06
Oxygen, &c.	6.46
	100.00

Estimating its calorific power as if the carbon were solid, it would give 17.50 lbs. water per lb. of oil, whilst on the basis of gaseous carbon it would give 22.18 lbs.

In addition to this point, that the physical state of liquid fuel represents so much latent heat, we have to remember that the carbon which it contains is also combined with hydrogen in hydrocarbons of some kind. These compounds of carbon are very readily dissociated by heat, especially in presence of steam of high temperature, and the result of this action is the formation of gaseous hydrocarbons which have a high calorific power. There is reason to believe that these reactions are accomplished with the expenditure of a moderate amount of "work" in the shape of heat. The temperature at which steam is dissociated *in the presence of gaseous carbon* must be less than that which is required with steam and solid carbon by at least the equivalent of the quantity of heat which becomes latent in gasifying the carbon in order that it may unite with the oxygen of the steam to complete the action; $H_2O + C = H_2 + CO$. When the steam is thus decomposed, there is nascent hydrogen in contact with carbon in the gaseous form in some of the heavier hydrocarbons, and there is thus present the opportunity for the formation of those gaseous hydrocarbons which are desired and which ignite at a higher temperature. The oxygen of the decomposed steam may either unite with part of the carbon to form carbonic oxide, or, if left uncombined in the primary reactions, it is ready to support combustion subsequently, and this it does, as is well known, with vigour.

For the proper carrying out of these reactions, certain conditions are necessary. The suitable temperature for the various reactions must be maintained, with sufficient time to enable them to be completed before the application of the heat of combustion is required (that is, before heat is abstracted by the requirements of the furnace). There must also be a proper relation between the steam and oil, whilst the air for combustion

should be carried to another point in the furnace, and not admitted with the steam and oil. In fact, full consideration of the matter points to some method of primary gasification of the oil with steam before combustion with air as the most likely to yield the highest results in constant work.

This account of the actions involved in the proper use of liquid fuel is confirmed by the evidence of the results of ordinary oil-gas manufacture. In one important particular—namely, the *quantity* of gas produced from oil—there is a great difference between the processes which we compare. Gas which is to be used for lighting must be cooled and purified from condensable matters before being stored and conveyed or distributed in pipes. Consequently, we find that in the processes of Pintsch, Keith, Rogers, and others, whilst about 150 cubic feet* of gas per gallon of oil used are stored for illuminating purposes, there is a liquid residue from the manufacture amounting to about 6 gallons per 1,000 cubic feet of gas made. These liquid hydrocarbons are quite suitable for gas-making, and in some cases the gas-making apparatus has been worked with them exclusively for the production of illuminating gas. In making use of liquid fuel for heating operations, it will readily be understood that all the original oil is completely gasified, so that the quantity of gas produced per gallon of oil is in that case probably from 250 to 300 cubic feet. The quality of gas made by the two methods may, however, be fairly considered as comparable, since the conditions can certainly be very nearly approximated in the two cases.

The following is an analysis of the gas produced by the apparatus of Messrs. Rogers, in which the oil is injected into red-hot retorts by steam, the oil used being a heavy hydrocarbon (its flashing point being given at 250° F.):—

Oxygen	0.73
Nitrogen	5.06
Luminiferous hydrocarbons	16.29
Marsh gas	46.17
Hydrogen	31.61
Carbonic oxide	0.14
	100.00

The following figures give the thermic value of this gas, on the supposition that the "luminous hydrocarbons" mentioned in the analysis are ethylene of the composition C_2H_4. If the composition C_4H_8 had been assumed for these hydrocarbons, the heating power would have been considerably higher.

Evaporative power of gas per lb. =	40.75 lbs.
" " " " cub. ft. =	1.622 "
Fahr. heat units per lb.	21,843
" " " cub. ft.	869.3
Calculated sp. gr. of gas	.4941

On the supposition that 25 to 27 cubic feet of such gas are produced per lb. of oil, these figures result in giving a theoretical evaporating power of *from* 40.5 *to* 43.79 *lbs. of water per lb. of oil* when completely turned into gas with steam.

This gas is stated to be of 56-candle power, and the results obtained from experiments made (at the Surgeons' Hall, Edinburgh, and in Glasgow by Dr. Wallace) on specimens of Scotch crude oils show that gas of even higher heating power may be obtained from oil of the kind used for fuel.

The following table (published in the "Glasgow Herald" of December 10, 1886) gives the results of these experiments collected and arranged

* Processes employing distillation alone, yield about 90 cubic feet per gallon of the intermediate quality of oil used.

for comparison with the yield of gas from several of the best Scotch cannel coals :—

	Gas per Ton. Cubic Feet.	Candle Power.	Value per Ton in lbs. Sperm.
West Lothian oil .840 sp. gr. . . .	24,922	60.15	5,139
,, ,, .890 ,, . . .	23,573	55.29	4,469
,, ,, .870 ,, . . .	24,383	56.26	4,702
,, ,, .870 ,, . . .	24,396	57.65	4,822
Westfield oil (crude)	16,755	49.03	2,815
Walkinshaw oil .653 sp. gr. . . .	19,464	40.23	2,683
Boghead coal	14,900	42.19	2,157
Cairntable coal (1872)	11,294	35.75	1,384⅓
Haywood coal (1884)	11,360	32.12	1,251.02
Lesmahagow, Auchenheath coal (1882) .	13,201	34.52	1,562.39

The quantities of gas yielded per ton, and the comparative values per ton of oil or coal in lbs. of sperm, are, of course, given on the basis of gas being made and stored for illuminating purposes. The table, however, reveals a store of heat-producing energy in oils of low quality which has not yet been utilized, if recognized.*

It is evident that it is on its ability to produce gas of high calorific power that the value of the liquid form of fuel rests, and that, in order to use this fuel successfully, efforts must be directed to the complete production and utilization of this gas.

The evidence before us points to the conclusion that with suitable apparatus it may be possible to obtain, continuously, results equivalent to an evaporation of from 40 to 50 lbs. of water per lb. of oil. Such results have been obtained at rare intervals in the experiments already made, but in general they have been considered as abnormal, and possibly incapable of a reasonable explanation.

MINOR FUELS.

In certain localities, especially where a better quality of fuel is not easily obtained, refuse vegetable matters are used as fuel for steam raising. Thus, spent tan has been frequently employed, and straw has also been used for portable agricultural boilers; both "megass," or the refuse from the sugar-cane, and cotton stalks are also among the substances used. All these materials are frequently referred to as minor fuels.

Prof. R. H. Thurston† investigated the performance of spent tan, both air-dried, weighing 42½ lbs. per cubic foot, and also containing from 55 to 59 per cent. of moisture as it came fresh from the leaches. By the combustion of wet tan, from 3⅛ to 4¼ lbs. of water were evaporated per lb. of tan; or, allowing for the excess of moisture in the tan, from 4.41 lbs. to 5.68 lbs. of water per lb. of air-dried tan. Péclet, quoted by Mr. D. K. Clark, found that five parts of oak-bark produce four parts of dry tan, and the heating power of perfectly dry tan, containing 15 per cent. of ash, is 6,100 British units, whilst that of tan in an ordinary state of dryness, containing 30 per cent. of water, is only 4,284 units.

The weight of water evaporated from and at 212° F. by 1 lb. of tan equivalent to these heating powers is:—

For perfectly dry tan	6.31 lbs.
For tan containing 30 per cent. of moisture . . .	4.44 ,,

Mr. J. Head‡ states that 3.25 to 3.75 lbs. of average dry wheat straw

* Refer also to W. Ivison Macadan on The Manufacture of Gas from Paraffin Oil, "Journ. Soc. Chem. Indus.," 1887, p. 199.

† "Min. Proc. Inst. C.E.," vol. xl. p. 347.

‡ *Ibid.*, vol. xlviii. p. 75, &c. Also "A Few Notes on the Portable Steam Engine," 1877.

will evaporate as much water in the same time as 1 lb. of good coal in a modern boiler.

The relative commercial value of the fuels is, however, as 1 to 5, because 3,300 lbs. straw, costing about 44*s.*, are equal to 943 lbs. coal at 8*s.* 6*d.*

Mr. Head also gives results with the use of "megass" and cotton stalks, and states generally that in portable engine boilers from $2\frac{1}{8}$ to $2\frac{1}{2}$ lbs. of water are evaporated per lb. of "megass" containing 16 per cent. of moisture, and from $2\frac{2}{3}$ to 3 lbs. of water per lb. of cotton stalks or brushwood.

THEORY OF HEAT.

Various theories have been held as to the intimate nature of heat. In what is probably the first scientific hypothesis on the subject, Bacon described heat as a vibratory motion of the smallest parts of bodies, and this view was in the main held until partly effaced, in the last century, by the suggestion that heat is an imponderable substance. In 1799, however, Davy and Rumford conclusively proved that heat can be generated by mere friction; the former described heat as being caused by motion, the latter identified it with motion.

Of the two alternative theories—the material and the dynamical—it may be correctly said that the capabilities of neither have been exhaustively studied. In certain cases, it is still perfectly possible to reason fruitfully on the theory that heat is an imponderable chemical substance; and on the other hand, the dynamical theory is not one of pure motion, but invariably considers the motion of material particles. The two theories are thus more closely akin than is usually supposed. If we adopt the current view that matter consists of atoms or molecules surrounded by ætherial envelopes (as the earth is surrounded by its atmosphere), we may raise the question, Is the motion that causes heat a motion of the atoms, of the ether, or of both? Physicists have found insurmountable obstacles in any other theory than that heat is some kind of atomic motion.

Modern ideas on the subject of heat derive most of their distinctness from the discussion of Mayer (1842) and the experiments of Joule (1843), who showed that heat is a perfectly measurable mechanical quantity; the latter investigator in fact determined the amount of heat produced in various ways, and in particular by friction between solids and liquids. This definite relation between heat and work—which indeed holds true whether work causes heat or heat causes work—is called the Mechanical Equivalent of Heat. It is quantitatively expressed in the following statements:—In order to raise the temperature of 1 pound of water 1 degree F., the mechanical energy to be expended is that of 772 pounds falling 1 foot: or in French units, 424 kilogram-metres are required to raise 1 kilo. of water 1° C. This result is commonly known as the first principle of thermodynamics.

Although this equivalence of heat and work may be regarded as certainly established, we can readily see that it is subject to what may be termed "actual" limitation. It can only hold good when we transfer heat from a warmer to a colder body, or, what is the same thing, when we transform heat of a higher temperature into heat of a lower temperature. It is the more quickly vibrating body which loses motion to the more slowly vibrating body. Thomson expresses this result as follows:—"It is impossible, by means of inanimate material agency, to derive mechanical effect from any portion of matter by cooling it below the temperature of the coldest of the surrounding objects." This is the second principle of thermodynamics.

Considerations as to the efficiency of engines mainly depend on the second principle. It is not sufficient to consider, for example, the heat

given out by the combustion of a fuel, unless we also bear in mind the temperature of the environment. In other words, the portion of the total energy of a fuel that can be thus exchanged for work, depends on the relative temperatures of the boiler and condenser. The mathematical expression of this law (for a perfect, or reversible engine) is—

$$\frac{W}{H} = \frac{T-t}{273+T};$$

where W represents the work performed by the engine, H the heat actually communicated to it, T is the temperature (C.°) of the boiler, and t that of the condenser. The fraction $\frac{W}{H}$ represents what is called the "efficiency" of the heat engine in mechanical units; and this evidently depends on the difference between the temperatures of the boiler and condenser.

The temperature $-273°$ C. has been approximated to, but not actually attained, experimentally. It is usually known by the name "absolute zero;" which implies that all bodies when at that temperature cannot in any way be regarded as sources of heat.

RELATIVE VALUE OF FUEL.

Different kinds of fuel are by no means capable of producing a like amount of heat, and it becomes both interesting and highly important to learn the methods which science has adopted for ascertaining their maximum heating effect. The results obtained from these researches are called the *theoretical calorific effect;* and in order to ascertain this, it is necessary to know the *quantity of heat* which a certain amount of fuel is capable of producing, and the *time* which is required for effecting that object. These two points furnish the idea of what is called *heating power*. The *value of the fuel* depends on its *heating power*, and its *price* at the time of consumption; it varies, therefore, in different localities, and can only be relatively fixed.

The determination of the first point (the quantity of heat) with accuracy is exceedingly difficult; but for practical purposes a knowledge of the *absolute* quantity is not required, it is sufficient to know how much the heat produced by one kind of fuel exceeds or falls short of that produced by another, the actual quantities produced by each being undetermined. Several methods have been employed at different times to ascertain this relative heating power. The more ancient, purely physical experiments, undertaken by the most distinguished men of science, were all conducted on the same principle, that of causing the whole of the heat which a burning substance or fuel emits, to act on a third body, in order to compare the action which the different kinds respectively had upon it. The apparatus by which this was done, is the well-known *calorimeter*. Lavoisier and Laplace caused the heat evolved in this apparatus to act on ice, and measured the amount of heat by the quantity of ice that was melted. At a later period, Count Rumford, to whom we are indebted for many experiments on fuel, used water instead of ice, and measured the heat by the increase of temperature produced in a given quantity of water. Both methods of determination are in fact the same, the quantity of heat which will melt 1 lb. of ice at 0°, being just sufficient, according to Lavoisier and Laplace, to raise the temperature of as much water (1 lb.) 75° C.;* or what is the same thing, to raise 0.75 lb. of water 100° C. Clement and Desormes have likewise shown, that an equal weight of aqueous vapour, whatever may be its temperature and tension, is always produced by one and the same amount of heat, and con-

* From the more recent and accurate experiments of de la Prevostaye and Desains as well as from those of Regnault, it appears that this number must be raised to 79°.

sequently always contains that same quantity; and, farther, the quantity of heat which water at 100° C. absorbs (latent heat) in a manner no longer indicated by the thermometer, in order to be converted into vapour, is 5.5 times (according to Rumford, 5.67) as much as would suffice to heat the same weight of water from 0° to 100° C. According to the later and more exact researches of Regnault this value is 5.367. It is therefore easy to calculate how much water would be converted into vapour by the heat that is required to melt 1 lb. of ice.

Rumford's experiments, which only extended to the different kinds of wood, led to the following results:

One Pound of the following Kinds of Wood, when burnt, will heat:	Pounds of Water from 0° to 100° C.
1. Lime-tree.	
Dry wood, 4 years old	34.707
,, ,, slightly dried	38.833
,, ,, strongly dried	40.131
2. Beech.	
Dry wood, 4 or 5 years old	33.798
,, ,, strongly dried	36.746
3. Elm.	
Wood, rather damp	32.147
,, dried, 4 or 5 years old	30.205
,, strongly dried	34.083
,, dried brown	30.900
4. Oak.	
Common firewood, in small shavings	26.272
The same in thicker shavings	25.590
,, thick shavings	24.478
,, dried in the air.	29.210
Very dry wood in thin shavings	29.838
,, ,, thicker ,,	26.227
5. Ash.	
Common dry wood	30.666
The same dried in air, shavings	33.720
The same, shavings dried in an oven	35.449
6. Sycamore.	
Strongly dried in an oven	36.117
7. Mountain Ash.	
Strongly dried in an oven	36.130
Dried brown	32.337
8. Bird Cherry.	
Dried wood	33.339
Strongly dried in an oven.	36.904
Dried brown	34.736
9. Fir (Deal).	
Ordinary dry wood	30.322
Well dried in the air, in shavings	34.000
Well dried in an oven, in shavings	37.379
Well dried brown, in shavings	33.358
Well dried, in thick shavings	28.695
10. Poplar.	
Wood dried in the ordinary manner	34.601
Wood strongly dried in an oven	37.161
11. Hornbeam.	
Dried wood (ordinary)	31.704

By means of instruments of the same kind, the following results have also been obtained:

1 lb. of hydrogen	will raise the temperature of	234	lbs. of water		from 0° to 100° C.
1 ,, pure carbon	,, ,,	72	,, ,,		
1 ,, wood charcoal	,, ,,	75	,, ,,		
1 ,, dry wood	,, ,,	36	,, ,,		
1 ,, wood containing 20 per cent. of water	,, ,,	27	,, ,,		
1 ,, good coal	,, ,,	60	,, ,,		
1 ,, peat	,, ,,	25—30	,, ,,		
1 ,, alcohol	,, ,,	67	,, ,,		
1 ,, ether	,, ,,	80	,, ,,		
1 ,, vegetable oil, rape oil, wax oil, &c.	,, ,,	95	,, ,,		

The same quantity of heat being required to raise the temperature of 100 lbs. of water 1° as in heating 1 lb. of water 100°, it follows from the above results, that—

1 lb. of hydrogen	will raise the temperature of	23,400	lbs. of water	1° C.
1 „ vegetable oil, rape-oil, wax, &c.	„	„	9,000—9,500	„	„	
1 „ ether	„	„	8,000	„	„	
1 „ pure charcoal	„	„	7,200	„	„	
1 „ wood charcoal	„	„	7,500	„	„	
1 „ alcohol	„	„	6,700	„	„	
1 „ good coal	„	„	6,000	„	„	
1 „ dry wood	„	„	3,600	„	„	
1 „ wood containing 20 per cent. moisture	„	„	2,700	„	„	
1 „ peat	„	„	2,500—3,000	„	„	

The numbers placed against the different combustibles in this table, or the quantities of water which 1 part of a combustible will raise 1° C. in temperature, represent units of heating power—the quantity of heat necessary to raise a given quantity (1 lb.) of water 1° C. being assumed as unity or the standard of comparison for the effects of heat.

If the heating effect of pure carbon be taken as unity, the relative heating values of the other combustibles will range as follows:

Hydrogen	3.24	Alcohol	0.92
Vegetable oil, &c.	1.23—1.30	Good coal	0.77—0.82
Ether	1.09	Dry wood	0.49
Gas-carbon	1.07	Wood with 20 per cent. water	0.37
Wood charcoal	1.02	Peat	0.35—0.41

It appears from this table that the absolute heating effect of hydrogen is nearly 3 times as great as that of carbon.

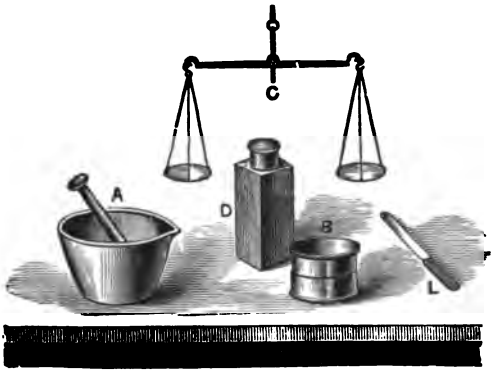
The greater the quantity of hydrogen, therefore, contained in any combustible body, the greater will be its heating effect.

Regnault's apparatus (see Ganot's "Physics," p. 356; "Chemistry, &c.," art. "Fuel," W. Mackenzie, Glasgow), although designed for the determination of specific heats, contains features illustrating the method of observing and measuring temperatures, and the precautions against error which are necessary.

Favre and Silbermann's calorimeter * (see Watts, "Dict. of Chemistry," Second Supplement, pp. 608, &c.) is likewise a delicate apparatus suitable specially for determining the calorific capacity of liquids, the latent heat of evaporation, and the heat disengaged in chemical action.

Thompson's calorimeter, represented in Figs. 217–219, is an instrument for determining the relative value of fuels—indeed, it is the only one generally employed for that purpose. It consists, as will be seen in the accompanying diagram, Fig. 218, of a glass jar, H, graduated to contain 1,934 grams of water. In this are inserted (1) a thermometer to indicate elevation of temperature, and (2) a cylindrical combustion chamber, G, capped and tapped at the top. The combustible to be examined (2 grams) is mixed as intimately as possible with 22 grams of a very dry mixture of 3 parts of potassic chlorate with 1 of

FIG. 217.



* See also W. Anderson, "On the Generation of Steam, &c.," Inst. C.E. Lectures on heat and its mechanical applications. Sessions 1883-84, p. 5.

nitrate, and introduced into a small cylindrical copper reservoir, E; a piece of nitrate of lead fuse, F, is added and lighted. The combustion chamber or cap is closed and instantly caused to cover the reservoir, and the whole is placed without delay in the water of the calorimeter. Gases soon issue from orifices at the lower edge of the chamber, and rise through the liquid, imparting their heat to it. When combustion has ceased, the *rise* in temperature of the water is observed; to this, one-tenth is added for the water-value of the calorimeter. The corrected number gives the number of grams of water, which a gram of the combustible can evaporate at the boiling point.

Fig. 218.

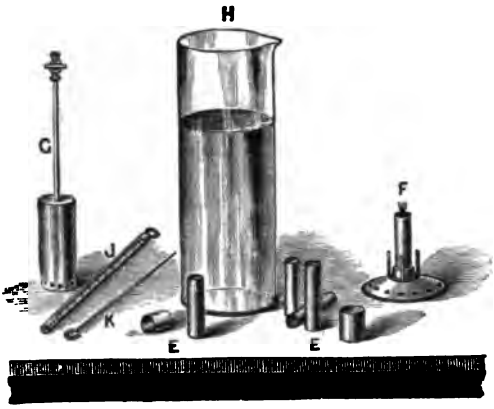


Fig. 219.

Calorimeter in Action.

Combustibles that burn too easily require the addition of 0.5–1 gram of china-clay, purified by roasting in air. The apparatus can, if desired, be calibrated by burning in it a known quantity of pure sulphur. Thompson's calorimeter is made by Wright, of Millbank Street, London, S.W.

Prof. F. Schwackhöfer has designed and constructed a calorimeter for determining the calorific power of coal or other fuel. It has a platinum combustion chamber divided into two parts, in the lower of which the sample is burned by means of oxygen gas, which is led into the apparatus. The heat is measured by the rise of temperature of a measured quantity of water. For full details of the apparatus, the original paper must be consulted in *Zeit. anal. Chem.*, vol. xxiii. p. 453, where it is described. A short abstract and illustration are given in "Jour. Soc. Chem. Indus.," 1885, p. 332. See also "Jour. Soc. Chem. Indus.," 1886, pp. 635–637, for description of Heisch and Folkard's instruments.

A most remarkable connection between the quantities of heat evolved, and the chemical process of combustion, was first pointed out by Welter in the calorimetrical experiments of Laplace, Lavoisier, Despretz, Rumford, and others, and gave rise to a new and more convenient method of determining the heating power. Welter observed that those quantities of a combustible body which require an equal amount of oxygen for combustion, evolve also equal quantities of heat, as is shown by the following examples:

1 lb. of:	will heat lbs. of Water from 0° to 100° C.	Or, 1 lb. of Oxygen in consuming:	will heat lbs. of Water from 0° to 100° C.
Hydrogen . . .	236.4 Despretz	0.125 lb.	2.955
Charcoal . . .	78.15 ,,	0.375 ,,	2.931
Perfectly dry wood . .	43.141 Rumford	0.724 ,,	3.093

In the greater number of combustible bodies, the differences observed were not greater than might have been anticipated from the difficulties attending all calorimetrical researches, whilst in others, as phosphorus, iron, &c., they were twice as great. Welter therefore drew the conclusion, that the oxygen required for the combustion of a body being in the same relation as the quantity of heat evolved, might fairly be made the measure of the heating power. In fact, we are led, *a priori*, to this supposition, if we consider that, on the one hand, the heat evolved must bear some relation to the mass of the body burnt; and, on the other, that oxygen may with equal propriety be considered the combustible, as the body with which it combines (the fuel). When, therefore, oxygen burns by means of carbon, wood, hydrogen, &c., the heat which is evolved must increase with the quantity of it that is consumed; or the same amount of heat is generated by a certain given weight of oxygen, whether that quantity be employed in converting carbon into carbonic acid, or hydrogen into water. The amount of heat generated can easily be calculated from the experimental results given at p. 333. For as

1 part of carbon requires for combustion $2\frac{2}{3}$ parts of oxygen, and
1 „ hydrogen „ „ 8 „ „

and

1 part of carbon will raise the temperature of 72 parts of water, and
1 „ hydrogen „ „ 234 „ „

from the freezing to the boiling point, it follows directly that

1 part of oxygen in burning carbon will heat $\frac{72}{2\frac{2}{3}} = 27.0$ parts of water,

1 part of oxygen in burning hydrogen will heat $\frac{234}{8} = 29.3$ „ „

from the freezing to the boiling point.

In round numbers, therefore, the heating effect of oxygen may be assumed at 28 or expressed in units of heating power at 2800.

Absolute Heating Effect.—If, therefore, the quantity of oxygen required by 1 part of a combustible be denoted by O, the absolute heating power of that combustible may be expressed by the equation

$$(1) \qquad A = 2800\, O$$

$$\text{or } A = 2800\, \frac{n}{a},$$

in which latter formula, n = the number of oxygen atoms with which the body combines during combustion, and a = the atomic weight of the substance, that of oxygen being = 1.

The number obtained by means of either of these equations consequently indicates the amount of water which will be raised 1° C. in temperature by the heat generated during the combustion of 1 part of the combustible body.

The formula may easily be extended for bodies containing more than one combustible element. Let a fuel contain $a\ b\ c\ d$ parts by weight of different combustible ingredients, which respectively combine with $O\ O'\ O''\ O'''$, parts by weight of oxygen, then

$$(2) \qquad A = 2800\,[a\,O + b\,O' + c\,O'' + \ldots.]$$

$$\text{or } A = 2800\left[a\frac{n}{a} + b\frac{n'}{\beta} + c\frac{n''}{\gamma} + \ldots.\right] \qquad (4)$$

In the latter formula $n\ n'\ n''$ . . . denote the number of oxygen atoms with which 1 part of the corresponding combustible bodies combines; $a\ \beta\ \gamma$ . . . denote the equivalent weights of those bodies.

The second formula is deduced from the first by making

$$O = \frac{n}{a},\ O' = \frac{n'}{\beta},\ O'' = \frac{n''}{\gamma} \ldots .$$

The general correctness of Welter's theory has not been proved, indeed recent researches (as will be stated presently) tend to invalidate it; but G. Bethke and F. Lürmann have advanced some considerations founded upon the latent heat of the gasification of carbon which go far to remove the doubts thrown upon it by these later researches. Berthier founded a practical process on Welter's theory to determine in one experiment the quantity of oxygen requisite for combustion, and thus the heating power of the combustible. It consists in mixing intimately a weighed quantity (10 grs.) of the combustible with a large excess (400 grs.) of pure litharge (protoxide of lead). The mixture is placed in a crucible, sufficiently capacious to contain 3 times the bulk of the mixture, and rendered impervious to the gases of the furnace by a coating of fire-clay or by a glaze, and is covered with an equal quantity of pure litharge. The crucible, being covered with a lid and placed on a support in a furnace, is slowly heated to redness, and when the gases which cause the mixture to swell considerably have escaped, the crucible is covered with fuel, and strongly heated for about ten minutes in order to collect the globules of reduced lead into a single button at the bottom of the mass of fused litharge. The oxygen of the oxide of lead combines with and burns the combustible ingredients of the fuel, leaving for every equivalent of oxygen consumed an equivalent of reduced metallic lead. It is, therefore, only necessary to weigh the metallic lead, which is easily separated from the fused litharge by a few strokes of the hammer, in order to discover the amount of oxygen consumed and the relative heating power of the fuel. If, however, it is required to ascertain the quantity of water heated up to 1° or 100° C., it is necessary to refer to the known calorimetric power of a single combustible body, and carbon is then usually made the standard of comparison. Now 1 part of pure carbon requires 2.666 parts of oxygen, which, taken from litharge, leave 34.5 parts of metallic lead; the same quantity of carbon, according to Despretz, is sufficient to heat 78.15 parts of water from 0° to 100°; so that every unit of lead that is reduced by any kind of fuel corresponds with $\frac{78.15}{34.5} = 2.265$ parts of water, which it can raise from 0° to 100° C.* Taking the corrected numerator 72.26 this becomes 2.095 parts.

An elementary analysis, in which the substance is completely consumed—its carbon being converted into carbonic acid and its hydrogen into water—affords a convenient means of calculating approximately its heating power, compared with that of carbon as unity.†

If H is made to denote the percentage amount of hydrogen, and C the percentage amount of carbon, in any kind of fuel containing only carbon and hydrogen, the heating power of hydrogen being approximately 4.25 times that of carbon, the absolute heating effect A of the fuel will be expressed by the formula:

$$A = 4.25\ H + C. \qquad (3)$$

But if, at the same time, along with carbon and hydrogen, the fuel also contains oxygen, and this is already in combination either with carbon or with hydrogen, it of course must diminish the absolute heating power of the fuel, and as 1 equiv. of carbon takes up 2.666, and 1 equiv. of hydrogen takes treble

* Practical experiments on a large scale, as well as elementary analysis, have shown that the determinations made with litharge are liable to a constant error, and afford results which are always about ¼ below the actual calorific power.

† See "On the Estimation of the Calorific Value of Solid and Liquid Fuel," by F. J. Rowan, "Journ. Soc. Chem. Ind.," 1888, p. 195.

that quantity—namely, 8 parts of oxygen—we have to deduct from the sum of both, the quantity of oxygen actually present in the combustible—that is, supposing it is known to be already in combination—in order to ascertain the quantity furnished from without, which then becomes the measure of the heating power; *e.g.*, in oak-wood there are: 0.4943 parts carbon, and 0.0607 hydrogen, which would give

$$0.4943 \times 2.666 + 0.0607 \times 8 = 1.318 + 0.485 = 1.803.$$

If the oxygen in the oak-wood, viz., 0.445, is deducted from that quantity, we obtain $1.803 - 0.445 = 1.358$ as the amount of oxygen required, corresponding to 17.58 of lead reduced, or to 39.8 of water, which would be heated to 100° C. by one part of oak-wood. Or, as 1 part of oxygen is combined in carbonic acid with $\frac{3}{8}$ parts of carbon and in water with $\frac{1}{8}$ of hydrogen, and we designate by O the quantity of oxygen contained in the combustible, its absolute heating effect A will be expressed by one or other of the following formulæ, according as the oxygen is supposed to detract from the heating effects of the carbon or hydrogen:

$$A = 4.25[H - \tfrac{1}{8} O] + C. \qquad (4)$$

To convert the product from either of these equations into units of heating power, it is only necessary to multiply by the heating power of carbon = 7226.

As an example, the heating power of alcohol may be thus calculated. The elementary composition of alcohol is expressed by the formula: C_2H_6O, and it contains in 100 parts:

Carbon	52.66
Hydrogen	12.90
Oxygen	34.44
	100.00

The one half of the oxygen in alcohol, according to the formula, is already combined with hydrogen to form water. The heating power of alcohol will consequently be =

$$4.25\ (0.129 - \tfrac{1}{8}.\tfrac{1}{2}.0.3444) + 0.5266 = 0.85,$$

which agrees very closely with the experimental number given in the table at p. 334.

Heating Power referred to Volume.—This property of a combustible is expressed by the amount of heat which a certain volume of the combustible yields during perfect combustion. The absolute heating power being ascertained, it is only necessary to multiply that by the specific gravity of the combustible in order to obtain its specific heating power.

The following table exhibits the specific heating power of the combustible bodies enumerated in the tables (p. 334), the heating power by volume of pure carbon (diamond) being = 100.

Pure carbon (diamond) . .	100	Dry wood	5.26
Good coal	33.00	Wood charcoal	4.94
Vegetable oil	30.20	Wood containing 20 per cent. moisture	4.91
Ether	21.10	Hydrogen	0.0077
Alcohol	19.80		

The specific gravities from which the numbers in the above table have been deduced are the following: Diamond = 3.5, coal = 1.5, vegetable oil = 0.92, ether = 0.72, alcohol = 0.8, dry wood = 0.4, wood with 20 per cent. moisture = 0.5, wood charcoal = 0.18, hydrogen (compared with water) = 0.00009.

For the specific gravity of porous substances, such as wood and wood charcoal, numbers have been taken which have reference to those substances in the usual state when their pores are filled with air.

PYROMETERS.

Pyrometrical Heating Effect.—The pyrometrical heating effect of a combustible is expressed by the degree of heat developed during its complete combustion. Various instruments have been constructed for the approximative estimation, in a direct manner, of the high degrees of temperature which most ordinary combustibles produce during combustion; but none of the older instruments, which were called *pyrometers*, attained such a degree of perfection that their indications could be considered trustworthy.

Wedgwood adapted the progressive contractility of clays at very elevated temperatures to the construction of the pyrometer which bears his name. The instrument consists of a plate of copper, upon which two strips of the same metal gradually converge to one point, between which small truncated cones of clay are inserted, these latter passing farther forward towards the point at which the two strips meet in proportion to the contraction which the clay has undergone by exposure to different high degrees of temperature. Great care is required in the preparation of the clay for these small cones; it should always be of the same composition, and, containing an equal amount of water, should be baked at the same temperature. The diminution of volume which clay sustains at higher temperatures is partly due to a loss of water, and partly to a closer agglomeration of the particles in obedience to some law yet unknown. Incipient redness has been adopted for the zero point on Wedgwood's scale, and is the point at which the cones, having been heated to that temperature, are arrested by the strips of metal 240 divisions are traced upon one of the strips beyond that point, each one of which corresponds to 72° of the centigrade thermometer (130° F.). In order to ascertain the temperature of a furnace by this pyrometer, one of the small clay cones is placed in a crucible, in which it is allowed to acquire the temperature of the furnace; it is then withdrawn, and when cool is inserted between the two metallic strips; the point at which its farther progress is arrested then indicates the temperature to which it has been exposed. The difficulty of securing at all times the same quality of clay, and consequently the same contraction for the same temperature, renders this pyrometer next to useless; indeed, it is now no longer in use in the Staffordshire potteries, where alone, at one time, it was extensively employed.

The constant temperature at which certain metals and alloys enter into fusion may be employed to a limited extent for estimating high temperatures. M. Princep employed 10 alloys of gold and silver, containing each an increase of $\frac{1}{10}$ of gold; and 100 alloys of gold with platinum, in which the latter metal is progressively increased by $\frac{1}{100}$th. By placing a number of these alloys in pieces of the size of a pin's head upon a cupel of bone-ash in which small cavities for the reception of each alloy have been made, and introducing this into any furnace, the temperature of which is to be determined, the alloy at which fusion has been arrested may be observed when the cupel is withdrawn. The temperature of two furnaces can thus be directly compared; but in order to arrive at a knowledge of the exact temperature of any, it is obviously necessary to ascertain the precise thermometrical degree at which each alloy enters into fusion. This has been done by M. Princep for the points of fusion of silver and several of the alloys of gold, by measuring the dilatation of air confined in a vessel of pure gold. The results of his experiments on these points are the following:

Red heat	649° C.	(1200° F.)
Orange heat	899 ,,	(1650 ,,)
Silver fuses	999 ,,	(1830 ,,)
Silver with $\frac{1}{10}$ gold	1648 ,,	(2998 ,,)
Silver with $\frac{1}{4}$ gold	1121 ,,	(2050 ,,)

Daniell proposed the linear expansion of platinum as a pyrometrical standard, and the mode of applying his instrument to the measurement of furnace temperatures is familiar to every student of the elements of natural philosophy.

For the accurate measurement of high temperatures, instruments similar to the air thermometer have been proposed by Deville and Troost and by Regnault, the essential modification being the employment of a vapour much heavier than air, and therefore susceptible of determination by the balance.

Deville and Troost's pyrometer consists of a sphere of refractory porcelain, having a capacity of about 500 c.c., and provided with a narrow tubulus, into which a stopper of the same porcelain fits loosely. Some iodine having been placed in the flask and the plug inserted, the whole is introduced into the place whose temperature is to be determined. Iodine vapour soon escapes from the flask, driving out all the air before it. In about twenty minutes the flask will have acquired its maximum temperature, and iodine will cease to be evolved. The plug is then sealed to the end of the tubulus by means of an oxyhydrogen blowpipe, and the flask cooled, cleaned, and weighed. The end of the tubulus is then broken under water, and the water which then enters the flask is weighed together with the flask. The flask, if necessary, is next filled entirely with water, and again weighed; lastly, it is weighed dry. The observer is now supposed to be in possession of the following information—viz.:

Temperature of the balance	t° C.
Height of barometer corrected	h mm.
Difference between weight of flask full of iodine vapour and flask full of air	gram
Capacity of flask	v c.c.
Residual air	a c.c.
Weight of 1 c.c. normal air	.001293 gram
Density of iodine vapour referred to air	8.716
Co-efficient of expansion of air (1° C.)	.00367
Co-efficient of cubical expansion of porcelain (1° C.) .	.0000108

and the temperature T is calculated as follows:—

$$I_w = \frac{(v-a).001293h}{(1+.00367t)760} + i$$

is the weight of iodine vapour at sealing; and the corresponding volume is—

$$I_v = \frac{I_w(1+.00367T)760}{.001293 \times 8.716h}.$$

Finally, we have the relation—

$$I_v + \frac{a(1+.00367T)760}{(1+.00367T)h} = v(1+.0000108T),$$

which only contains one unknown quantity T, the temperature sought.

Regnault's mercury pyrometer is similar in principle. It consists of a wrought-iron bottle in which mercury is placed, and the mouth of which can be closed by a perforated stopper sliding horizontally. The capacity of the flask is about a litre or half a litre. After acquiring the temperature of a heated space (a point not so easy to ascertain as in the case of the iodine pyrometer), the stopper is slid over the orifice and the flask is removed and cooled. The mercury remaining in the bottle is removed and weighed. The following are the requisite data:—

v = capacity of the bottle in c.c. at 0° C.;
k = co-efficient of cubical expansion of iron;

h = corrected barometric reading when the flask is withdrawn from the furnace;
d = density of mercury vapour;
p = grams of mercury remaining in the bottle.

The weight of mercury vapour which fills the flask at T (the required temperature) is—

$$p = \frac{v(1 + kT).0012932hd}{(1 + .00367T)760};$$

hence,

$$\frac{1 + kT}{1 + .00367T} = \frac{760p}{.0012932vdh} = M\frac{p}{h},$$

M being a constant for the same bottle. We have, therefore—

$$T = \frac{1 - M\frac{p}{h}}{.00367M\frac{p}{h} - k}.$$

Ducomet proposed the employment of a series of alloys of known melting point. These are introduced into a tube (or space otherwise protected) having the temperature required to be known. As their melting points range above and below the temperature of the medium, it is easy to ascertain this approximately either by ocular observation or by feeling the alloys with an iron rod. It must be remarked that the same samples of an alloy will not retain the same melting point after repeated trials, so that they should be used once only, or at most a very few times.

This method has been greatly developed by Carnelley. From a long series of determinations which he has published in the Transactions of the Chemical Society for 1878 and 1880, the following may be selected as likely to prove of greatest service:—

Substance.	Melting Point C.	Substance.	Melting Point C.
Sodic chlorate	302	Cadmic bromide	571
Sodic nitrate	316	Potassic iodate	582
Potassic nitrate	339	Baric nitrate	593
Potassic chlorate	359	Potassic perchlorate	610
Plumbic iodide	383	Sodic iodide	628
Zinc bromide	394	Strontic nitrate	645
Cadmic iodide	404	Calcic bromide	676
Baric chlorate	414	Magnesic bromide	695
Argentic bromide	427	Sodic bromide	708
Cuprous chloride	434	Calcic chloride	719
Zinc iodide	446	Potassic chloride	734
Argentic chloride	451	Molybdic trioxide	759
Tri-argentic phosphate	482	Sodic chloride	772
Cupric chloride	498	Potassic fluoride	789
Strontic iodide	507	Sodic carbonate	814
Argentic iodide	527	Potassic carbonate	834
Cadmic chloride	541	Sodic sulphate	861
Borax	561	Calcic fluoride	902

The following numbers will also be found of value:—

Tin	228	Lead	325
Bismuth	264	Zinc	412
Cadmium	315	Aluminium	700

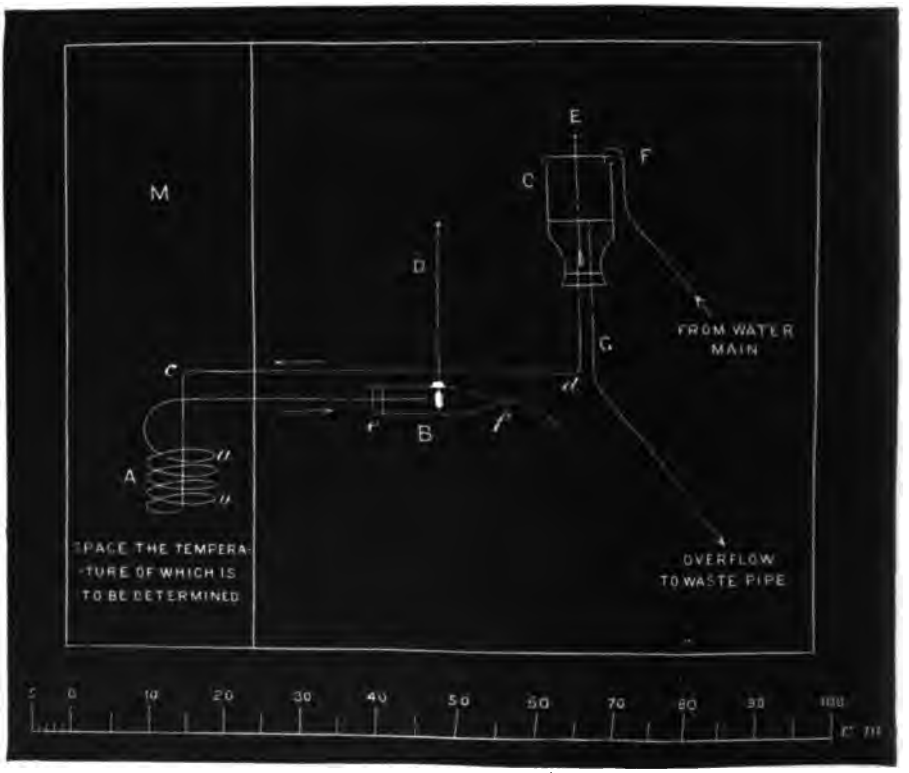
By the preceding methods, the temperature of a heated space can be ascertained at a given time, but not continuously. Several pyrometers have, however, been invented to enable large numbers of consecutive observations to be taken.

Gauntlett avails himself of the difference between the expansions of two rods as a means of moving a system of springs which cause the hand on a dial to rotate. For temperatures up to 1000°, one rod is of iron, the other of brass; for the range 1000°–1500°, the brass rod is exchanged for one of fire-clay.

The Trampler pyrometer is similar in principle. A hard, but very porous rod of graphite is inserted in an iron tube, which, on exposure to heat, expands much more than does the rod. This excess of expansion is indicated by magnifying gear.

Carnelley and Burton claim to have invented in 1879 (though they did not then publish it) a water-current pyrometer. The arrangement is of an extremely simple character (Fig. 220). A current of water flows from a cis-

FIG. 220.



tern, C, of constant level through a tube of thin copper, *d c*. At the place, A, where the temperature is to be determined, the tube is coiled for several turns, *a b*; the effluent water is led through a small chamber, B, against the bulb of a small mercurial thermometer, D, therein contained. The difference of temperature between the inflowing and effluent water is observed, and this difference furnishes the temperature required by reference to a table previously constructed from experiments at known temperatures. As uniform flow and capacity cannot possibly be maintained in a copper tube under the conditions indicated, it is obvious that the greatest possible care should be taken with the arbitrary graduation, on which the use of this instrument wholly depends.

Saintignon's pyrometer seems to be identical with this. Amagat also, in 1882, invented a water-current pyrometer of the same kind, in which he caused the water to flow first downwards and then upwards in the heated medium. Messrs. Boulier Brothers patented in 1883 another form of this instrument. The water is caused to circulate in a casing of thin copper, and the pipes which carry on the circulation are both led into a refrigerator, through which flows a rapid current of cold water. The temperature of the water is ascertained at its exit from the casing and from the refrigerator, the difference between these two readings determining the temperature of the casing.

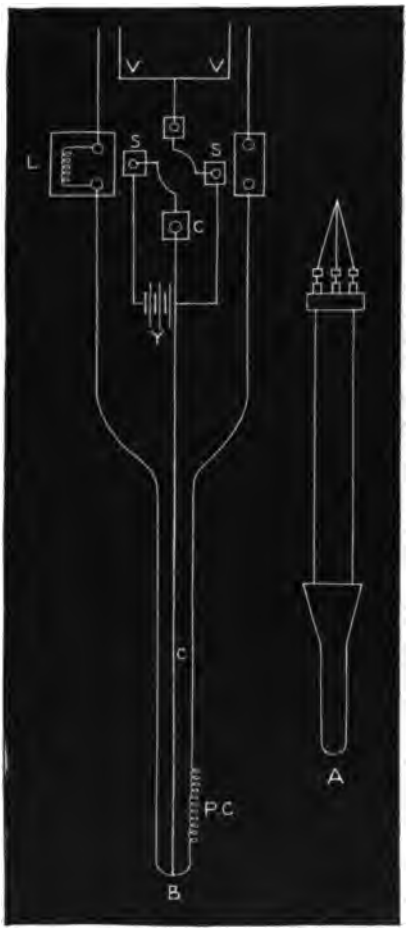
It is probable that a water-current pyrometer might be made to give good indications if used for the same furnace with a steady flow of pure water—or at least of water yielding little or no deposit when heated.

Siemens' electrical pyrometer dates from 1860, when its inventor utilized the effect of heat in producing increased resistance in a protected copper wire, to detect heating in a telegraph cable coiled in a ship's hold. As applied to high temperatures, it is constructed as follows:—Upon a cylinder of hard baked pipeclay a double thread is cut, and in this are coiled two platinum wires, united at the lower end, whose resistance is to give the desired indication. The wire has a diameter of .01 inch, and a resistance of about 3.6 units per yard. The clay cylinder occupies the lower end of an iron or platinum external case, which again is inserted in a long tube of wrought iron, employed as a handle. Connections with upper leading wires are made at the upper end of the case, there being in all three leading wires.

Instead of employing a galvanometer to measure the resistance effect, two voltameter tubes are used, in which dilute sulphuric acid is subjected to electrolysis. These are sold with the instrument, and are accompanied by a table, in which the temperatures corresponding with given volumes of the mixed gases are entered.

Fig. 221 will assist in comprehending the nature of the arrangement.

FIG. 221.

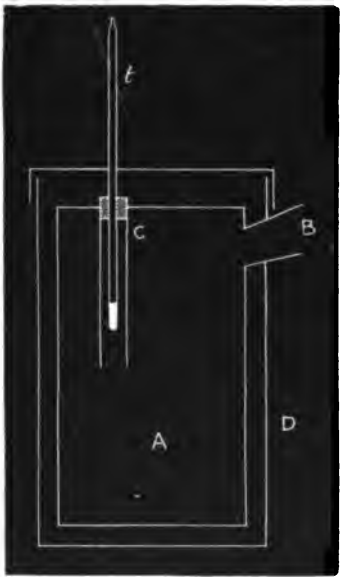


A is the encased pyrometer, with handle and leading wires, B is a plan of the circuit and its divisions.
V V are the two voltameter branches.
Y is the battery.
S S binding screws connecting battery to commutator.
C C conductor in undivided circuit.
L standard resistance coil.
P C pyrometer coil.

It will be observed that the principle of the instrument consists in comparing the volume of mixed gases given off in one voltameter by passing an electric current through a known resistance, with the corresponding volume in a precisely similar voltameter simultaneously affected by the resistance of the heated wire. In continued practical use, the platinum undergoes some slight physical change, causing the zero indication to rise, and involving consequently a re-adjustment of the table. This is particularly noticeable after very high temperatures have been measured. Siemens' pyrometer has been used in various technical operations.

The calorimetric method has been employed with considerable success as a means of pyrometry. If a body of known specific heat be raised to an unknown temperature and then immersed in an always constant volume of water, a thermometer placed in the water will give readings which are a definite function of the unknown temperature. Almost any calorimeter, if well jacketed to prevent fluctuations of temperature, will do for this purpose; and the rise of temperature of the thermometer can be converted into measured temperatures by graduating the instrument with a constant weight of suitable material raised to known temperatures. Thus, Bystrom employed a platinum ball placed inside a clay tube, which was duly exposed to the temperature required to be determined; the ball was then suddenly transferred to a water calorimeter arbitrarily graduated as above described. Siemens used a thermometer with a detached scale, so that the zero of the scale could always be set at the initial height of the mercury in the thermometer; this scale gave the unknown temperature by direct reading. Unfortunately, the scale was graduated on the assumption that the specific heat of metals does not alter with temperature.

FIG. 222.



The greater part of modern pyrometry is effected by means of Weinhold's instrument. Fig. 222 shows a modification of it which has been found very useful in manufacturing operations. It consists of an inner vessel, A, containing a litre of water, and constructed of common tin-plate. This has two apertures—one at B, through which the pyrometric iron balls are thrown in, and another at C, in which is fixed a tin tube, protecting a thermometer t (reading directly to tenths centigrade). The outer vessel D also consists of tin-plate, and is closed by a lid. Cotton-wool is tightly packed between the two vessels, which are about half an inch apart. In an actual determination, three balls of wrought iron, weighing about 20 grams apiece, are placed in a wrought-iron or clay tube, then raised to the desired temperature therein, and suddenly transferred into the water contained in the inner vessel. The aperture B is quickly closed with an india-rubber cork, and the whole well shaken. The highest reading of the thermometer is next read. If a reading has been taken just before the experiment, the rise is, of course, known. The temperature x is calculated as follows:—Let

W = weight of water in pyrometer,

w = weight of iron balls,

C = water value of pyrometer (about 20 grams),

T = highest reading of calorimeter,
t = initial do.,
s = mean specific heat of wrought iron between T and x:

then

$$x = \frac{W + C}{w}(T - t)\frac{1}{s} + t_2.$$

Inasmuch, however, as the s in this equation involves a knowledge of x, an assumption has first to be made that x has a certain value; and the s corresponding with this is used in the calculation. The result of the calculation gives a new value of x, with which corresponds a better value of s, to be employed in a second similar calculation; the third approximation is in general sufficiently close. This method gives results which are accurate at high temperatures to about ± 10°, provided the iron balls are renewed sufficiently often. A table of values of s is subjoined.

Mean Specific Heat of Wrought Iron

Between Temperatures t_1 and t_2, calculated from the Formula

$$\frac{w}{t_2 - t_1} = 0.105907 + 0.00003269\,(t_2 + t_1) + 0.000000022159\left[\frac{t_2^2 + t_1^2 + (t_2 + t_1)^2}{2}\right].$$

(Weinhold, *Ann. der Phys. u. Chem.*, vol. cxlix p. 214.)

t_2	For t_1 = 20° C.	For t_1 = 25° C.	t_2	For t_1 = 20° C.	For t_1 = 25° C.	t_2	For t_1 = 20° C.	For t_1 = 25° C.	t_2	For t_1 = 20° C.	For t_1 = 25° C.
350°	.120881	.121088	388°	.122762	.122973	426°	.124706	.124921	464°	.126714	.126934
1	929	137	9	812	.123023	7	758	973	5	768	988
2	977	186	390	862	074	8	810	.125025	6	822	.127042
3	.121025	235	1	912	124	9	862	077	7	876	096
4	074	284	2	963	175	430	914	130	8	930	150
5	123	333	3	.123013	226	1	966	182	9	984	204
6	172	382	4	064	276	2	.125018	235	0	.127038	258
7	221	431	5	114	327	3	071	287	1	092	312
8	270	480	6	165	378	4	123	340	2	146	366
9	319	529	7	215	429	5	176	392	3	200	421
360	369	578	8	266	480	6	229	445	4	255	475
1	418	627	9	317	531	7	281	497	5	309	529
2	467	677	400	368	581	8	334	550	476	363	584
3	516	726	1	419	632	9	386	602	7	417	638
4	565	776	2	470	683	440	438	655	8	472	692
5	614	825	3	521	734	1	490	708	9	526	746
6	663	875	4	572	785	2	543	761	480	580	801
7	713	924	5	623	836	3	596	814	1	635	855
8	763	974	6	674	888	4	649	867	2	689	910
9	813	.122023	7	725	939	5	702	920	3	744	964
370	863	072	8	776	990	6	755	973	4	799	.128019
1	912	121	9	828	.124041	7	808	.126026	5	853	073
2	961	171	410	879	093	8	861	079	6	908	128
3	.122010	221	1	930	145	9	914	132	7	962	183
4	059	271	2	982	196	450	967	185	8	.128017	238
5	109	321	3	.124033	248	1	.126020	238	9	072	293
6	159	371	4	085	299	2	073	292	490	126	348
7	209	421	5	136	351	3	126	345	1	181	403
8	259	471	6	188	402	4	180	399	2	236	458
9	310	521	7	239	454	5	233	452	3	291	513
380	360	571	8	291	505	6	287	505	4	346	568
1	410	621	9	342	557	7	340	559	5	401	624
2	460	671	420	394	609	8	393	612	6	456	679
3	510	722	1	446	661	9	446	666	7	511	734
4	561	772	2	498	713	460	500	719	8	566	789
5	611	822	3	550	765	1	553	772	9	621	844
6	661	873	4	602	817	2	606	826	500	676	900
7	712	923	5	654	869	3	660	880	1	731	955

MEAN SPECIFIC HEAT OF WROUGHT IRON—(*continued*).

t_2	For t_1= 20° C.	For t_1= 25° C.	t_2	For t_1= 20° C.	For t_1= 25° C.	t_2	For t_1= 20° C.	For t_1= 25° C.	t_2	For t_1= 20° C.	For t_1= 25° C.
°			°			°			°		
502	.128787	.129011	527	.130185	.130413	552	.131611	.131840	577	.133064	.133297
3	842	066	8	242	470	3	669	898	8	123	356
4	898	122	9	298	526	4	726	956	9	182	415
5	953	178	530	354	583	5	784	.132013	580	241	473
6	.129009	234	1	410	639	6	842	071	1	300	532
7	064	290	2	467	696	7	899	129	2	359	591
8	120	346	3	524	753	8	957	187	3	418	650
9	175	402	4	581	810	9	.132015	245	4	477	709
510	231	457	5	638	867	560	073	303	5	536	769
1	286	513	6	695	924	1	131	361	6	595	828
2	342	569	7	752	981	2	189	419	7	654	887
3	398	625	8	809	.131038	3	247	478	8	713	946
4	454	681	9	866	095	4	305	536	9	772	.134005
5	510	737	540	923	152	5	364	594	590	832	065
6	566	793	1	980	209	6	422	653	1	891	125
7	622	849	2	.131037	266	7	480	711	2	950	185
8	678	905	3	095	324	8	538	769	3	.134009	244
9	734	961	4	152	381	9	596	827	4	069	304
520	790	.130018	5	209	438	570	655	886	5	128	364
1	846	074	6	267	496	1	713	944	6	188	423
2	903	131	7	324	553	2	771	.133003	7	247	483
3	959	187	8	381	610	3	830	062	8	307	543
4	.130016	244	9	438	667	4	888	121	9	366	603
5	072	300	550	496	725	5	947	180			
6	129	357	1	553	782	6	.133005	238			

t_2	For t_1= 30° C.	For t_1= 35° C.	t_2	For t_1= 30° C.	For t_1= 35° C.	t_2	For t_1= 30° C.	For t_1= 35° C.	t_2	For t_1= 30° C.	For t_1= 35° C.
°			°			°			°		
600	.134898	.135135	626	.136472	.136712	652	.138076	.138319	678	.139710	.139956
1	958	195	7	533	774	3	139	381	9	774	.140020
2	.135019	256	8	595	835	4	201	444	680	838	084
3	079	317	9	657	897	5	264	507	1	901	147
4	140	377	630	718	959	6	327	569	2	965	211
5	200	438	1	780	.137020	7	389	632	3	.140029	275
6	260	498	2	841	082	8	452	696	4	093	339
7	321	559	3	903	144	9	515	758	5	157	403
8	381	620	4	965	205	660	577	821	6	221	467
9	442	680	5	.137026	267	1	640	883	7	284	531
610	502	741	6	088	329	2	703	947	8	349	595
1	563	801	7	149	391	3	766	.139009	9	412	659
2	624	862	8	211	452	4	828	072	690	476	723
3	684	922	9	273	514	5	891	135	1	540	787
4	745	983	640	334	576	6	957	198	2	604	851
5	805	.136044	1	396	637	7	.139016	261	3	667	915
6	866	104	2	457	699	8	079	324	4	731	979
7	926	165	3	519	760	9	142	386	5	795	.141043
8	987	225	4	581	822	670	204	449	6	859	107
9	.136047	286	5	642	884	1	267	512	7	923	171
620	108	347	6	704	945	2	330	575	8	987	235
1	168	407	7	765	.138006	3	393	638	9	.141050	299
2	229	468	8	827	069	4	455	701	700	114	362
3	289	529	9	887	130	5	518	764			
4	350	589	650	950	193	6	582	828			
5	410	650	1	.138013	256	7	646	892			

Amongst other means of measuring temperatures may be mentioned the well-known thermometer of Berthelot, which consists of a simple upright reservoir of glass, closed by a narrow tube, bent twice at right angles, and terminating in a U gauge containing mercury. The gauge carries a scale empirically graduated by placing the air reservoir in the vapour of liquids at known boiling point, the expansion of the air altering the level of the mercury

in the gauge. Recknagel and Mills, however, have shown that in instruments of this kind the zero cannot probably remain constant for more than a day, on account of entry of air into the reservoir against the mercurial pressure. This thermometer, therefore, is not adapted for use in works.

The tension principle has also been proposed by Messrs. Schäffer and Budenberg. Their instruments consist of extremely strong reservoirs, containing ether, water, or mercury, according to the conditions under which the pyrometer is to be employed. The reservoirs are jointed to common Bourdon manometers, filled with the same liquids, and consequently really register tensions. In this case, everything depends on the tightness of the joint, and the impermeability of the metallic envelope to vapour of the liquid at a high temperature. In actual trial for charcoal kilns and other purposes, these instruments have, as might be expected, proved leaky and untrustworthy; but it is probable that for the lower part of their scale they would show more steady and accurate indications.

The pyrometers chiefly used for measuring the heat of the hot blast consist of strips of metal soldered together and bent into a helical form; one end of the helix is connected with a hand running over a dial; the other is attached to the wall of a box. A change of temperature causes the helix to coil or uncoil, as the case may be, and thus effects a movement of the hand over the dial. Combined strips of brass and steel (Kahl's instrument) will measure temperatures up to 440° C. The dial is graduated in the lower part of its scale by comparison with a mercurial thermometer, and in the upper by inference from the lower. A new pyrometer for measuring hot blast temperatures, which has stood the test of continuous work for over two years in Messrs. Addie's Langloan Ironworks at Coatbridge, N.B., has been described under the name of Frew's pyrometer. It makes use of the expansion of the air due to heat to move a coloured liquid over a scale properly graduated. It is an ingenious form of air thermometer,* with some modifications, which the description and illustration published in "Engineering" of January 8, 1886, will make plain.

References may be made to the following papers, which contain suggestions of interest—viz., "On a New Form of Gas Thermometer," by G. Beilby ("Jour. Soc. Chem. Ind.," 1885, p. 40), and "Description of an Improved Thermometer for taking High Temperatures," by J. Murrie (*Ibid.*, pp. 45, 189, 655); Crookes and Röhrig's "Metallurgy," vol. iii. pp. 320–347; "On a New Mode of measuring High Temperatures," by John Wilson ("Proc. Inst. Mech. Engineers," 1852, p. 53). See, also, "Pyrometers" in "Jour. Iron and Steel Inst.," vols. i. 1884, pp. 195, 196, 240–242; i. 1885, p. 325; i. 1886, p. 207.

None of the earlier instruments or methods for the direct estimation of high degrees of temperature are of any real practical value, and we are consequently referred, in general, to the elementary composition of combustibles, in order to estimate their pyrometrical heating values approximatively by calculation.

The entire amount of heat developed during the combustion of a combustible must necessarily be transferred to the products of combustion. The absolute heating power of the different combustibles has been expressed above by the heat which they respectively communicate to a given amount of water; if this known amount of heat be transferred from water to the products of combustion, we must obviously obtain the mean temperature of the combustion, or the pyrometrical value of the fuel consumed. The specific heat of water, in reference to that of the gases generated, forming an important element in the calculation.

* A description of a delicate instrument of this kind is given in *Zeit. physikal. Chem.*, vol. i. pp. 79, 97 (abstracted in "Journ. Chem. Soc.," vol. liv. p. 331).

The following example, in which it is proposed to estimate the pyrometrical heating power of carbon by calculation will illustrate this method, and in order to complicate the calculation as little as possible, the combustion is assumed to take place in pure oxygen gas.

Carbon requires $2\frac{8}{3}$ times its weight of oxygen for complete conversion into carbonic acid. The absolute heating power is consequently according to formula (p. 336) $3000.2\frac{8}{3} = 8000$. The heat generated during the combustion of 1 part of carbon will, therefore, raise the temperature of 8000 parts of water 1° of the centigrade thermometer, or will heat 1 part of water from 0° to 8000° C., or will raise $3\frac{8}{3}$ parts of water from 0° C. to $\frac{8000}{3\frac{8}{3}} = 2182°$ C. During the combustion of 1 part of carbon $3\frac{8}{3}$ parts of carbonic acid are produced, to which the entire amount of heat generated during the combustion, except the radiant heat, is transferred. If, therefore, the specific heat of carbonic acid were identical with that of water, the temperature of the gas would be 2182° C.; but the specific heat of carbonic acid as compared with water as unity is = 0.2210; the temperature of the carbonic acid produced by the combustion will consequently be in the inverse ratio, or $\frac{2182}{0.2210} = 9873°$ C. The pyrometrical heating power of carbon burning in oxygen gas is therefore 9873° C. A general formula may be constructed in a similar manner for the pyrometrical heating power of any combustible. If O represent the amount of oxygen with which 1 part of a combustible combines on burning and s the specific heat of the products of combustion, its pyrometrical heating power will be expressed by

$$P = 3000\frac{o}{(1+O)s} \qquad (5)$$

or $P = 3000\frac{n}{(a+n)s}$ when O is made $\frac{n}{a}$ as explained at a former page.

The pyrometrical heating power of a simple combustible body is therefore expressed by its absolute heating power in heat units divided by the product of the relative weight of its combustion-product and its specific heat.

This formula has reference to a simple combustible body burning in oxygen gas. In order to establish similar formulæ for compound combustible bodies, the following physical law must be known:

When A, B, C, D, represent different quantities of the same fluid, possessing temperatures corresponding to t, t', t'', t''' degrees C, the mean temperature of the mixture of all these fluids will be

$$\frac{At + Bt' + Ct'' + Dt''' \ldots .}{A + B + C + D}; \qquad (R)$$

if these fluids are of different chemical constitution, and consequently have different specific heats, then when s, s', s'', s''', express their corresponding capacities for heat, the mean temperature of the mixture will be expressed by

$$\frac{Ast + Bs't' + Cs''t'' + Ds'''t''' + \ldots}{As + Bs' + Cs'' + Ds''' + \ldots} \qquad (R')$$

With the aid of this formula, the problem in question may be solved in the following manner:

Let the fuel consist of a, b, c, d, parts by weight of the different

combustible bodies. Then retaining the mode of expression employed on a former occasion—

By the combustion of:	The product of combustion will be obtained
a	$a(1+O) = A$
b	$b(1+O') = B$
c	$c(1+O'') = C$
d	$d(1+O''') = D$
&c.	&c.

The degree of temperature produced by the combustion of a, b, c, d, or the temperature of the products of combustion (A, B, C, D) are easily obtained by means of the formula (5)

By the combustion of:	Degree of temperature obtained.
a	$3000\,\frac{O}{(1+O)s} = t$
b	$3000\,\frac{O'}{(1+O')s'} = t'$
c	$3000\,\frac{O''}{(1+O'')s''} = t''$
d	$3000\,\frac{O'''}{(1+O''')s'''} = t'''$
&c.	&c.

If these values for A, B, C, and D, and for t, t', t'', t''', are now inserted in the formula R', we obtain :

$$P = 3000\,\frac{aO+bO'+cO''+dO'''+\ldots.}{a(1+O)s+b(1+O')s'+c(1+O'')s''+d(1+O''')s'''+\ldots.} \qquad (6a)$$

and when O is made $= \frac{n}{a}$, $O = \frac{n'}{\beta}$, $O'' = \frac{n''}{\gamma}\ldots$

$$P = 3000\,\frac{a\frac{n}{a}+b\frac{n'}{\beta}+c\frac{n''}{\gamma}+d\frac{n'''}{\delta}+\ldots.}{a\left(1+\frac{n}{a}\right)s+b\left(1+\frac{n'}{\beta}\right)s'+c\left(1+\frac{n''}{\gamma}\right)s''+d\left(1+\frac{n'''}{\delta}\right)s''''+\ldots.} \qquad (6b)$$

The pyrometrical heating power of a compound combustible body is therefore expressed by its absolute heating effect in units of heat divided by the sum of the relative weights of all the products of combustion of its constituents, each of these being multiplied by its corresponding specific heat.

If the combustion takes place in atmospheric air instead of in oxygen, the effect is very much lessened, as the whole of the nitrogen in the air which accompanies the oxygen consumed is necessarily mixed with the products of combustion. It therefore becomes necessary to ascertain what proportion of nitrogen is left for each proportion of oxygen consumed, and likewise what mean temperature will result from the mixture of that amount of nitrogen which, without any serious error, we may assume to be at 0° C., with the other products of combustion.

When carbon burns in oxygen gas, the temperature of the product of combustion was calculated at 9873° C. Atmospheric air is composed in 100 parts of 23.1 oxygen to 76.9 nitrogen ; to each part of oxygen there are therefore $\frac{76.9}{23.1} = 3.33$ parts of nitrogen. One part of carbon consumes in

burning to carbonic acid $2\frac{2}{3}$ parts of oxygen, there will consequently be $2\frac{2}{3} \cdot 3.33 = 8.88$ parts of nitrogen liberated when 1 part of carbon is burned, and this nitrogen will be mixed with the carbonic acid, which if alone would have acquired the temperature of 9873° C.

The specific heat of carbonic acid is = 0.2210, and that of nitrogen = 0.2754.

According to formula (R') the temperature must therefore be expressed by

$$\frac{3\frac{2}{3} \times 9873 \times 0.2210 + 8.88 \times 0 \times 0.2754}{3\frac{2}{3} \times 0.2210 + 8.88 \times 0.2754} = 2458° \text{ C.}$$

The general formula for the pyrometrical heating power obtained in this manner will therefore be expressed by:

$$P = 3000 \frac{O}{(1+O)s + 0.917\,O} \qquad \text{or} \qquad P = 3000 \frac{n}{(a+n)s + 0.917\,n} \qquad (7)$$

In order to obtain a similar general formula for the combustion of a compound combustible body in atmospheric air, the following physical law must be adverted to. When $A\ B\ C\ D\ \ldots$ denote different quantities of fluids, all possessing the same temperature t, but different capacities for heat $s\ s'\ s''\ s'''\ \ldots$, and to these already mixed fluids a fluid Q is added, the temperature of which = T, and its specific heat = σ, the mean temperature of the whole will be expressed by:

$$\frac{(As + Bs' + Cs'' + Ds''' + \ldots)\,t + Q \cdot \sigma \cdot T}{As + Bs' + Cs'' + Ds''' + \ldots + Q \cdot \sigma} \qquad (R'')$$

The application of this formula will be readily understood. $A\ B\ C\ D\ldots$ represent the different products of combustion of the constituents $a\ b\ c\ d\ldots$ of the fuel; $s\ s'\ s''\ s'''\ \ldots$ the specific heat of the products of combustion; t is the temperature produced by the combustion of the fuel in oxygen, therefore = P in the formula (6); Q = the quantity of nitrogen separated from the air with the oxygen consumed; P = the specific heat of the nitrogen, and T the original temperature of the nitrogen assumed at 0° C. There must consequently be interpolated in the formula (R''):

$$A = a(1+O),\ B = (1+O'),\ C = c(1+O'') \ldots\ldots$$
$$s = s,\ s' = s',\ s'' = s'',\ \ldots\ldots$$
$$t = \frac{aO + bO' + cO'' + \ldots}{a(1+O)s + b(1+O')s' + c(1+O'')s'' + \ldots}$$
$$Q = 3.33\,(aO + bO' + cO'' + \ldots)$$
$$\sigma = 0.2754$$
$$T = O$$

With these substitutions we obtain:

$$P = 3000 \frac{aO + bO' + cO'' + dO''' + \ldots}{[a(1+O)s + b(1+O')s' + c(1+O'')s'' + \ldots] + 0.917[aO + bO' + cO'' + \ldots]} \qquad (8a)$$

or when $O = \frac{n}{a}$, $O' = \frac{n'}{\beta}$, $O'' = \frac{n''}{\gamma}$, &c., &c.

$$P = 3000 \frac{a\frac{n}{a} + b\frac{n'}{\beta} + c\frac{n''}{\gamma} + d\frac{n'''}{\delta} + \ldots}{\left[a\left(1+\frac{n}{a}\right)s + b\left(1+\frac{n'}{\beta}\right)s' + c\left(1+\frac{n''}{\gamma}\right)s'' + \ldots\right] + 0.917\left[a\frac{n}{a} + b\frac{n'}{\beta} + c\frac{n''}{\gamma} + \ldots\right]} \qquad (8b)$$

In these formulæ, which will be subsequently applied:

$a\ b\ c\ d\ \ldots$ denote the relative proportions by weight of the different combustible bodies of which fuel is composed, the total quantity being = 1.

$O\ O'\ O''\ \ldots$ denote the relative quantities of oxygen with which those proportions combine during combustion.

$n\ n'\ n''\ \ldots$ denote the number of equivalents of oxygen with which 1 equivalent of the different combustible substances combine.

$\alpha\ \beta\ \gamma\ \ldots$ are the atomic weights of these bodies, the atomic weight of oxygen being = 1.

$s\ s'\ s''\ \ldots$ denote the specific heats of the products of combustion of the bodies consumed.

The following table contains the pyrometrical heating powers of several simple and compound bodies calculated according to these formulæ, both for combustion in pure oxygen and in atmospheric air.

	Pyrometrical Heating Power expressed in 0° C.	
	In Oxygen.	In Atmospheric Air.
Carbon	9873°	2458°
Vegetable oil	6024	2122
Ethylene	5793	2090
Ether (C_4H_5O)	5484	2049
Marsh gas	4800	1945
Alcohol* (C_4H_5O, HO)	4521	1910
Hydrogen	3172	1611

Absolute accuracy has not been attempted in calculating these heating values, several circumstances which influence the result more or less having been neglected. Amongst these may be noticed that, for the co-efficients $s\ s'\ s''$s the values which have been introduced have reference to the specific heats of these gases at the ordinary temperature of the air. The co-efficients are consequently too small, the capacities increasing with the temperature; they should have been calculated for the temperature of combustion. As these only occur in the denominators of the formulæ, the pyrometrical heating powers will be somewhat too high. Again, the combustibles before entering into combustion all require to be heated to a certain extent. Thus, oil for instance requires a temperature of 315° C. at its burning surface, at which temperature it is decomposed into gaseous products; cold oil does not burn, but the gases do so which are generated at a temperature of 315°, which temperature they consequently possess, and this will have a corresponding effect in raising the pyrometrical value. This cause can exert but little influence on the calculated heating effect of ether and alcohol, as these liquids boil at comparatively low temperatures, and none whatever on the combustible gases hydrogen and marsh gas. In the case of carbon, however, it is the red-hot carbon alone which burns. The two former of these causes can exert but little influence on the pyrometrical value of fuel, but the latter increases to some extent the temperature of combustion of carbon and oil. Again, the prime unit or factor 3,000 is not improbably too high, and would be advantageously exchanged for the lower value 2,800.

Although not absolutely accurate, the following general conclusions may be drawn from the results collated in the table above.

1. The pyrometrical heating power of carbon is greater, that of hydrogen smaller, than that of any one of the other combustibles. The combustion-

* In calculating the pyrometrical effect of alcohol, it has been taken into consideration that it contains 19.37 per cent. of water ready formed, the evaporation of which diminishes its heating effect. The latent heat of the vapour of water has not been taken into account.

temperature of carbon is more than 3 times as great as that of hydrogen. The inflammable fuels must therefore all have a lower pyrometrical heating power than those which burn without flame, or than more or less pure carbon.

2. The pyrometrical heating power of different combustible bodies whose property of combustibility depends on the carbon and hydrogen they contain, is greater in proportion to the amount of carbon which they contain.

3. The difference between the pyrometrical heating powers of different fuels is very much more considerable when the combustion takes place in oxygen gas than when it occurs in the air. Thus between carbon and hydrogen, when burnt in oxygen gas, there is a difference of 6000° C., whilst in atmospheric air the difference does not exceed 800° C.

It appears anomalous that the pyrometrical heating power of carbon should be 3 times as great as that of hydrogen, while the absolute heating powers of the two substances are precisely in an opposite ratio. The cause of this lies partly in the specific heat of aqueous vapour being nearly 4 times as great as that of carbonic acid, and more especially in the circumstance that 1 part of hydrogen produces in burning 9 parts of aqueous vapour, while 1 part of carbon yields only $3\frac{2}{3}$ parts of carbonic acid.

It must also be noticed that the combustion-temperatures stated in the table above have reference to that locality either in immediate contact with the fuel or in the flame, where the actual combustion takes place. Unfavourable circumstances may confine this to a very limited compass, and the pyrometrical effect will apparently be diminished in proportion.

In the preceding calculations, the heating power has been expressed by the quantity of water heated to 1° C. by the heat evolved during the combustion of 1 part of the combustible; but, practically, where fuel is employed for other purposes than that of raising the temperature of water, as in all metallurgical operations, the effect is very much diminished. In the apparatus employed by Rumford and others for estimating the absolute heating power, the products of combustion escape at temperatures very little above that of the water heated. The steam produced by the combustion of the hydrogen in the combustible is condensed into the state of water, and the large amount of heat that was latent in the steam is, therefore, expended in raising the number denoting its heating power. When the combustible is employed in the furnace for producing much higher temperatures than that of boiling water, the water produced by combustion escapes in the state of steam, carrying with it its latent heat, and diminishing by so much the heating effect of the fuel. The formulæ above given will therefore require modification.

It has been proved by experiment that the quantity of heat required to evaporate 1 part of water from 100° C. is very nearly $5\frac{1}{2}$ times as great as the quantity required to raise 1 part of water from 0° to 100° C. In correcting the formula for the absolute heating effect of a combustible, the total quantity of hygroscopic and chemically combined water, as well as that produced during combustion must therefore be multiplied by $5\frac{1}{2}.100 = 550$, and the product subtracted from the previously ascertained number. If the latter be denoted by A, the corrected number by a, and the total amount of water by W, we obtain:

$$a = A - 550\ W. \qquad (9)$$

If σ denote the corrected and S the previously calculated specific heating effect, and if π denote the corrected and P the originally calculated pyrometrical heating effect, we obtain the following proportions:

$$S : \sigma = A \text{ to } a$$
$$P : \pi = A \text{ to } a$$

whence

$$a = \frac{a}{A} S \qquad (10)$$

$$\pi = \frac{a}{A} P \qquad (11)$$

In the following table (taken from Scheerer's *Metallurgie*) the different heating effects of combustibles which contain water or form water during combustion, are calculated with the corrections.

In the column of absolute heating effects, the heating effect of carbon is taken as unity. The numbers for the specific heating effects are the products of the absolute heating effects and the respective specific qualities of the combustibles. The pyrometrical effects are expressed in degrees of the centigrade thermometer. Dulong's determinations of the heating power of hydrogen, carbonic oxide, marsh gas, and olefiant gas have been adopted as the more correct, and the numbers hitherto obtained by Welter's law are quite inadequate to account for the effects produced in practice.

	Heating Effect.		
	Absolute.	Specific.	Pyrometrical.
Wood.			
Air-dried wood (with 20 per cent. hygroscopic moisture)	0.36	—	1575
Kiln-dried wood (with 10 per cent. hygroscopic moisture)	0.41	—	1675
Kiln-dried wood (without hygroscopic moisture)	0.47	—	1750
White beech*	—	0.28	—
Oak	—	0.26	—
Oak	—	0.25	—
Ash	—	0.24	—
Maple, birch, bird-cherry	—	0.23	—
Red beech, horse chestnut, elm, white-thorn	—	0.21	—
Scotch fir, alder	—	0.20	—
Sallow	—	0.19	—
Willow	—	0.18	—
Spruce fir, silver fir, larch	—	0.17	—
Lime, aspen	—	0.16	—
Black poplar, Italian poplar	—	0.14	—
Turf.—Peat.			
Imperfectly air-dried turf (with 30 per cent. hygroscopic water and 10 per cent. of ash)	0.37	—	1575
Best air-dried turf (25 per cent. moisture and no ash)	0.47	—	1750
Kiln-dried turf (no moisture and 15 per cent. ash)	0.55	—	1975
Best kiln-dried turf (without moisture and ash)	0.65	—	2000
Lignite.—Brown coal.			
Air-dried, fibrous lignite (20 per cent. moisture and no ash)	0.48	0.55	1800
The same (20 per cent. moisture and 10 per cent. ash)	0.43	—	—
Air-dried, earthy lignite (20 per cent. moisture and no ash)	0.61	0.79	1975
The same (20 per cent moisture and 10 per cent. ash)	0.55	—	—
Air-dried lignite, conchoidal fracture (20 per cent. moisture and no ash)	0.69	0.83	2050
Air-dried lignite, conchoidal fracture (20 per cent. moisture and 10 per cent. ash)	0.62	—	—
Kiln-dried, fibrous lignite (20 per cent. moisture and no ash)	0.61	—	2025
The same (20 per cent. moisture and 10 per cent. ash)	0.55	—	—

* The specific heating effects of all these woods are calculated from specimens in an air-dried condition.

HEATING EFFECT OF FUELS—(*continued*).

	Heating Effect.		
	Absolute.	Specific.	Pyrometrical.
Lignite.—Brown coal—(*continued*).			
Kiln-dried earthy lignite (20 per cent. moisture and no ash)	0.76	—	2125
The same (20 per cent. moisture and 10 per cent. ash)	0.69	—	—
Kild-dried conchoidal lignite (20 per cent. moisture and no ash)	0.85	—	2200
The same (20 per cent. moisture and 10 per cent. ash)	0.76	—	—
Coal.			
Sand coal (5 per cent. moisture and 5 per cent. ash)	0.79	1.06	2200
Sinter coal (5 per cent. moisture and 5 per cent. ash)	0.89	0.16	2250
Caking coal (5 per cent. moisture and 5 per cent. ash)	0.93	1.17	2300
Anthracite (5 per cent. moisture and 5 per cent. ash)	0.96	1.44	2350
Wood charcoal.			
Air-dried black charcoal (12 per cent. moisture and 3 per cent. ash)	0.97	—	2450
Perfectly dry ditto (3 per cent. of ash)	0.84	—	2350
Air-dried red charcoal (10 per cent. moisture, 1½ per cent. ash)	0.72	—	2200
Perfectly dry red charcoal	0.64	—	2100
Charcoal from Birch (No moisture and 3 per cent. of ash.)	—	0.20	—
Charcoal from Ash, wild service (No moisture and 3 per cent. of ash.)	—	0.19	—
Charcoal from Red beech, white beech, elm (No moisture and 3 per cent. of ash.)	—	0.18	—
Charcoal from Red fir (No moisture and 3 per cent. of ash.)	—	0.17	—
Charcoal from Maple (No moisture and 3 per cent. of ash.)	—	0.16	—
Charcoal from Oak, pear-tree (No moisture and 3 per cent. of ash.)	—	0.15	—
Charcoal from Alder (No moisture and 3 per cent. of ash.)	—	0.13	—
Charcoal from Lime (No moisture and 3 per cent. of ash.)	—	0.10	—
Peat charcoal.			
Worst description of air-dried peat charcoal (10 per cent. moisture and 56 per cent. ash)	0.85	—	2050
Best air-dried peat charcoal (10 per cent. moisture, 4 per cent. ash)	0.83	—	2350
Coke.			
Good coke (10 per cent. moisture and 5 per cent. ash)	0.84	—	2350
Best ditto (5 per cent. moisture and 3 per cent. ash)	0.92	—	2400
Ditto (no moisture and 3 per cent. ash)	0.97	—	2450
Sand-coke (no moisture, 5 per cent. ash)	—	0.46	—
Sinter-coke (no moisture, 5 per cent. ash)	—	0.41	—
Caking-coke (no moisture, 5 per cent. ash)	—	0.33	—
Gaseous combustibles. (Furnace gases.)			
Gases from wood charcoal	0.108	0.000140	1675
Ditto „ „ „	0.080	0.000104	1450
Gases from coke	0.107	0.000139	1750
Gases from coal	0.205	0.000267	1850
(Generator gases.)			
Gases from wood charcoal	0.115	0.000150	1775
Gas from wood	0.136	0.000177	1850
Ditto „ „	0.124	0.000161	1575
Gas from turf	0.092	0.000120	1525
Gas from coke	0.110	0.000143	1775

A summary view of these results is given in the following table:—

	Heating Effect.		
	Absolute.	Specific.	Pyrometrical.
Gaseous combustibles	0.08—0.205	0.00010—0.00027	1450—1850
Wood	0 36—0.47	0.14—0.28	1575—1750
Turf	0.37—0.65	—	1575—2000
Lignite	0.43—0.85	—.	1800—2200
Coal (5 per cent. moisture and 5 per cent. ash)	0.79—0.96	1.06—1.44	2200—2350
Peat charcoal	0.83—0.85	—	2050—2350
Wood charcoal	0.64—0.97	0.10—0.20	2100—2450
Coke (containing not above 5 per cent. ash)	0.84—0.97	0.33—0.46	2350—2450

The calculations from which these numbers result have been made on the assumption that the combustibles are entirely consumed, which certainly never occurs in practice, and the numbers must, therefore, be practically somewhat too high; they are likewise supposed to burn during a very short space of time, and give out during each successive period of that time, the same amount of heat, which we also know not to be practically the case—the process of dry distillation and the combustion of the inflammable gases always preceding the more intense heat of the glowing charcoal. Combustibles containing a large amount of ash are prevented from burning completely, by the impediment the ash offers to the draught, and to such as burn with a very smoky flame it is difficult to afford sufficient air to prevent a loss from unconsumed carbon. The effect of the gaseous combustibles is reduced below the calculated number by a certain amount of aqueous vapour, nitrogen and carbonic acid which they contain. This affects the gases evolved from wood and coal more than those from charred combustibles, and is in some measure compensated by the high temperature possessed by the combustibles before ignition.

Welter's law has been conveniently applied to calculate the theoretical heating power of combustibles of which the composition is accurately known. Recent experiments, however, conducted with every precaution to avoid error, by Messrs. Favre and Silbermann, by Grassi, Andrews, Thomsen and others, have proved that the heat evolved by a given weight of oxygen is not the same when different substances enter into combination with it and are consumed.

The absolute heating power of carbon, in being converted into carbonic acid, was found by Grassi between 7,632 and 7,801, by Favre and Silbermann at 8,086, by Andrews at 7,881, the older experimenters had fixed it at 7,800; in round numbers, it may therefore still be assumed at 8,000. When carbon burns to form carbonic oxide, the heating effect was estimated by Grassi at 2,480.

The following are the results of different experimentalists with reference to the absolute heating effect of hydrogen.

26,640 Despretz, Lavoisier, and Clement.
34,800 Dulong.
34,188 Favre and Silbermann.
34,656 Grassi.
33,808 Andrews.

The first number would indicate an amount of heat treble that afforded by carbon, and this has generally been assumed as the absolute heating effect of hydrogen. The last four results, which corroborate each other, and which have been obtained by more accurate methods, would increase the

absolute heating effect of hydrogen to nearly 4½ times that of carbon, or 36,000, which may be taken in round numbers as the actual effect.

The absolute heating effects of carbonic oxide, marsh gas, and olefiant gas have not been definitively settled even by the recent careful experiments; the results varying as follows:

Carbonic oxide.	2,403—2,466 Dulong, Favre and Silbermann. 2,431 Andrews. 1,857—1,876 (sp. gr. of carb. oxide taken at 0.9678) Dalton and Grassi. 1,710 according to Welter's theory.
Marsh gas.	6,375 Dalton 13,223 (sp. gr. 0.5589) Dulong. 13,108 Andrews. 13,158 Favre and Silbermann. 10,945 Grassi. 12,000 according to Welter's theory.
Olefiant gas.	6,600 Dalton. 12,172 (sp. gr. 0.9675) Dulong. 11,942 Andrews. 11,900 Favre and Silbermann. 8,557 Grassi. 10,290 according to Welter's theory.

When, therefore, as is probable from these results, the absolute heating power of carbon is taken in round numbers = 8,000, that of hydrogen = 36,000, that of carbonic oxide = 2,404—2,466 or = 1,857—1,876, that of marsh gas = 13,158—13,223, and that of olefiant gas = 11,900—12,172, and when the quantity of heat produced by the union of 1 part of oxygen with carbon in forming carbonic acid is taken as = 1, we then obtain the following relative heating powers:

1 Part of Oxygen produces in combining with:	Relative Heating Power.
Carbon	1.00
Hydrogen	1.50
Carbonic oxide	1.44 or 1.10
Marsh gas	1.10
Olefiant gas	1.17

These numbers, which are the co-efficients of intensity, show how far Welter's law deviates from the results of experiments. The formulæ for calculating the heating power of a combustible according to Welter's law will therefore require modification in order to obtain the actual effect.

The requisite alteration applies chiefly to the co-efficients of intensity, and those for carbon and hydrogen being different from those for carbonic oxide, marsh gas, &c., it is desirable to construct separate formulæ for the two classes of combustibles, the solid and gaseous.

There is, however, much force in the point raised by G. Bethke and F. W. Lürmann (in their paper on "Welter's Law and the Latent Heat of the Gasification of Carbon," in the Journal of the Society of German Engineers, 1885) to the effect that those who have condemned Welter's law as incorrect have not considered the amount of heat which is rendered latent when carbon passes from the solid to the gaseous state. They give a demonstration, from which we quote, that the law holds good whether hydrogen or carbon be burned with oxygen, and they hazard the supposition that it may hold good for all other chemical combinations of oxygen. They remark that "when one part by weight of hydrogen combines with eight parts by weight of oxygen to form water, one part by weight of oxygen in this case produces $\frac{33,600}{8} = 4,200$ thermal units.

"Again, one part by weight of carbon monoxide combines with $\frac{4}{7}$ parts by

weight of oxygen to form carbon dioxide, and in this case one part by weight of oxygen produces $\frac{2,400}{\frac{4}{7}} = 4,200$ thermal units, or the same quantity of heat.

"Similarly it happens that one part by weight of oxygen by burning from carbon to carbon monoxide produces $\frac{2,400}{\frac{4}{3}} = 1,800$ thermal units, and by burning from carbon monoxide to dioxide $\frac{8,000}{\frac{8}{3}} = 3,000$ thermal units.

"These last numbers are quite right, for the standard values for the heats of combustion have been determined by many exact experiments, but up till now no one has taken into consideration that by the combustion of solid carbon to the gaseous compounds carbon monoxide and dioxide a certain quantity of heat must be rendered latent which does not appear in the combustion experiments, and consequently the actual value seems up to the present time not to have been arrived at.* This latent heat of gasification of carbon can, however, be calculated as follows:—

"Let us consider the combustion of carbon monoxide, which is a gaseous body containing carbon in the gaseous state. It consists of $\frac{3}{7}$ parts by weight of carbon and $\frac{4}{7}$ parts by weight of oxygen. This latter of course contributes nothing to the heat of combustion when more oxygen is added. The fresh supply of oxygen attacks the carbon which exists as monoxide, so that on burning carbon monoxide to dioxide $\frac{4}{7}$ parts by weight of oxygen combine with $\frac{3}{7}$ parts by weight of gaseous carbon, and produce thereby a quantity of heat equal to 2,400 thermal units. This makes for one part by weight of carbon in the gaseous form $\frac{2,400}{\frac{3}{7}} = 5,600$ thermal units. Experiments on combustion have shown that one part by weight of solid carbon on combustion with oxygen to carbon monoxide yields 2,400 thermal units. The difference therefore is $5,600 - 2,400 = 3,200$ thermal units, which is the quantity of heat rendered latent in converting the carbon from the solid to the gaseous state.

"Taking this into consideration in calculating the heat of combustion of carbon, it follows that one part by weight of solid carbon produces on burning to carbon monoxide gas 5,600 thermal units, of which 3,200 are latent and 2,400 sensible. Moreover, one part by weight of solid carbon on burning to carbon dioxide produces 11,200 thermal units, of which 3,200 are latent and 8,000 sensible. In both cases it appears that the oxygen in the combustion produces 4,200 thermal units as in the case of the gaseous bodies carbon monoxide and hydrogen. Thus by the combustion of carbon to carbon monoxide $\frac{5,600}{\frac{4}{3}} = 4,200$ thermal units, and by the combustion of carbon to carbon dioxide $\frac{11,200}{\frac{8}{3}} = 4,200$ thermal units are obtained.

"Welter's law thus holds good throughout for combustible bodies in the gaseous state.

"When burning solid bodies to the gaseous form, we must introduce into the calculation the latent heat of gasification.

"Welter's law also admits of being put in the following form which gives a simple relation between the heats of combustion of different bodies:—On combustion with oxygen every simple or compound body develops a quantity of heat = 33,600 thermal units (the heat of combustion of hydrogen to water)

* These authors seem to have overlooked the able and exhaustive paper on Combustion published by M. E. Minary in *Publication Industrielle des Machines outils et appareils* (Paris, 1868), vol. 18. M. Minary enters fully into the question of the latent heat of the gasification of carbon in that paper.

divided by the atomic weight of the body and multiplied by the number of parts of oxygen which produce the combustion—thus

$$H_2 + O = \frac{33,600}{1} = 33,600 \text{ thermal units}$$

$$C + O = \frac{33,600}{6} = 5,600 \quad \text{,,} \quad \text{,,}$$

$$C + 2O = \frac{33,600}{6} \times 2 = 11,200 \quad \text{,,} \quad \text{,,}$$

$$CO + O = \frac{33,600}{14} = 2,400 \text{ thermal units."}$$

These authors conclude by saying that they purpose instituting an inquiry into the question whether Welter's law holds good for every chemical combination.

FORMULÆ FOR THE ABSOLUTE HEATING EFFECT.

a. **For solid fuels,** containing carbon, hydrogen, nitrogen, water and ash. The heating effect of a fuel containing by weight c parts of carbon, h of hydrogen, w water chemically combined, and w' of hygroscopic water may be calculated from the following formula, admitting that 1 part of carbon requires $2\frac{8}{3} = 2.67$ parts of oxygen for complete combustion, and 1 part of hydrogen requires 8 of oxygen.

$$A = 3,000\,[c \,.\, 2.67 + 1.5 \,.\, h \,.\, 8] - 550\,[9 \,.\, h + w + w'] \qquad (12)$$

The above formula gives the heating power in units of heat: in order to make a comparison with that of carbon as unity, the result must be divided by 8,000, the absolute heating effect of carbon, the negative element in the formula having reference to the correction for the latent heat of aqueous vapour.

b. **For gaseous combustibles** containing carbonic oxide, hydrogen, marsh gas, olefiant gas, nitrogen, carbonic acid and aqueous vapour. The heating power of a fuel of this description containing by weight k parts of carbonic oxide, h of hydrogen, g of marsh gas, o of olefiant gas, n of nitrogen, k carbonic acid and w aqueous vapour will be obtained by means of the following formula, admitting that 1 part of carbonic oxide combines with 0.57 parts of oxygen; 1 part of hydrogen with 8 of oxygen; 1 part of marsh gas with 4 parts of oxygen; 1 part of olefiant gas with 3.43 of oxygen; and that 1 part of marsh gas in burning produces 2.25 parts of water, and 1 part of olefiant gas 1.29 parts of water:

$$A = 3,000\,[x \,.\, k \,.\, o \,.\, 57 + 1.5 \,.\, h \,.\, 8 + 1.1 \,.\, g \,.\, 4 + + 1.17 \,.\, o \,.\, 3.43] - 550\,[g \,.\, h + 2.25 \,.\, g + 1.29 \,.\, o \,. + w]. \qquad (13)$$

The co-efficient of intensity for carbonic oxide is represented by x in the formula, as it still remains questionable whether it is 1.44 or 1.1.

The corrected formulæ for the specific heating effect are obtained from the above by multiplying the results into the respective specific gravities.

The formulæ for the pyrometric heating effect are easily deduced from those for the absolute effect, the latter being made = A we obtain

a. For solid combustibles:

$$P = \frac{A}{3.67 \,.\, cs + (g \,.\, h \,. + w + w')s' + [n + 3.33\,(2.67 \,.\, c \,. + 8 \,.\, h)]s'' + a \,.\, s'''} \qquad (14)$$

In this formula, s expresses the specific heat of carbonic acid, s' the specific heat of aqueous vapour, s'' the specific heat of nitrogen, and s''' the specific heat of the ash. The nitrogen which may possibly be contained in the fuel is represented by n and the ash by a.

For gaseous fuels, the following formula is obtained, when the absolute heating effect is $= A$, and 1 part of carbonic oxide is converted into 1.57 parts of carbonic acid; 1 part of marsh gas into 2.75 parts of carbonic acid and 2.25 of water; and 1 part of olefiant gas gives 3.14 parts of carbonic acid and 1.29 parts of water:

$$P = \frac{A}{\Sigma (K)\, s + \Sigma (w)\, s' + \Sigma (n)\, s''} \qquad (15)$$

$$\Sigma (K) = K + 1.57 \,.\, k + 2.75 \,.\, g + 3.14 \,.\, o$$
$$\Sigma (w) = w + 9 \,.\, h + 2.25 \,.\, g + 1.29 \,.\, o$$
$$\Sigma (n) = n + 3.33\ (o \,.\, 57 \,.\, k + 8 \,.\, h + 4 \,.\, g + 3.43 \,.\, o).$$

The letters in the formula apply to the same magnitudes as in the previous formula for the absolute heating effect, with the exceptions of s, s' and s'', which denote respectively the capacities for heat of carbonic acid, aqueous vapour and nitrogen.

The formulæ (14) and (15) are calculated for combustion occurring in atmospheric air; if the combustion takes place in oxygen gas, the magnitude multiplied by s'' in the denominator of the fraction has only to be made $= o$ in order to obtain the corresponding heating effect.

The pyrometrical heating effects of the following substances, calculated by R. Bunsen* from similar formulæ, are expressed as follows:

	In Oxygen.		In Air.	
Carbon	9,873° C.	17,803.4° F.	2,458° C.	4,456.4° F.
Carbonic oxide . . .	7,067	12,752.6	3,042	5,507.6
Olefiant gas	9,187	16,568.6	5,413	9,775.4
Marsh gas	7,851	14,103.8	5,329	9,624 2
Hydrogen	8,061	14,541.8	3,259	5,898.2

Bunsen remarks that "these numbers represent the temperatures which the various gases attain on combustion with exactly the requisite amount of oxygen or air, supposing that the inflamed gases can freely expand, as is the case in an open flame. If, on the contrary, the combustion occurs in a closed space, under circumstances in which the volume, and not the pressure of the gas, remains constant, the temperature of the combustion will be totally different."

If the determinations of Dulong, Favre and Silbermann for the absolute heating effect of carbonic oxide be correct, the remarkable and apparently paradoxical fact would be established, that carbonic oxide burning in atmospheric air produces a greater intensity of heat than carbon itself. The circumstance is however explained, not only by the high absolute heating power of carbonic oxide, but by the lesser amount of gaseous products of combustion that result; 1 part by weight of carbonic oxide producing only 2.47 parts of gaseous products, whilst 1 part of carbon produces 12.57 parts when the nitrogen separated from the air is included.

The pyrometric heating effect of carbon in being converted into carbonic oxide may be calculated from the absolute heating effect of that gas, as estimated by Favre and Silbermann, which amounted to 2480: then

$$P = \frac{2{,}480}{2\tfrac{1}{3}\ 0.288' + 3\tfrac{1}{3} \,.\, 1\tfrac{1}{3} \,.\, 0.275} = 1{,}310°\ \mathrm{C}$$

1 part of carbon combines with $1\frac{1}{3}$rd parts of oxygen to form $2\frac{1}{3}$rd parts of carbonic oxide; the specific heat of this gas is 0.288, that of nitrogen being 0.275.

The specific heats introduced above are those observed by De la Roche

* "Gasometry," p. 242, edition 1857.

and Bérard. Suermann, Apjohn and others have arrived at different numbers for the specific heats of several gases, which, if adopted, will slightly alter the results.

The values of different fuels, as ascertained approximately by Berthier's plan by himself and others, are given in the following tables (I.–VIII.).

I. WOOD.

Species of Wood.	Dried in the Ordinary Manner. Berthier.		Containing 9 per Cent. Water. Winkler.		Perfectly Dried. Schödler and Petersen.			
	lbs. of Lead reduced by 1 lb. of Wood.	lbs. of Water which 1 lb. can heat from 0° to 100° C.	lbs. of Lead reduced by 1 lb. of Wood.	lbs. of Water heated by 1 lb. from 0° to 100° C.	lbs. of Oxygen required for the Complete Combustion of 1 lb.	lbs. of Water consequently heated from 0° to 100° C.	Quantity of Air at 19° C. required to consume completely 1 lb. in lbs.	in C. F. Hessian.
1 part Oak wood	12.5	28.3	14.05	31.82	1.358	39.82	5.83	154.4
,, Ash ,,	—	—	14.96	33.89	1.356	39.76	5.82	154.2
,, Sycamore ,,	13.1	29.7	14.16	32.07	1.394	40.85	5.98	148.4
,, Beech ,,	13 7	31.0	14.00	31.71	1.346	39.44	5.78	152.9
,, Birch ,,	14 0	31.7	14.08	31.90	1.356	39.73	5 82	153.0
,, Elm ,,	—	—	14.50	32.84	1.418	41.55	6.08	101.1
,, Poplar ,,	—	—	13.04	29.54	1.390	40.72	5.96	157.9
,, Lime-tree ,,	—	—	14.48	32.80	1.429	41.87	6.13	162.3
,, Willow ,,	—	—	13.10	29.67	1.352	39.61	5.80	153.6
,, Fir ,,	14.5	32.8	13.86	31.39	1.408	41.25	6.04	160.0
,, Pine ,,	13 7	31.0	13.88	31.44	1.392	40.82	5.98	158.2
,, Scotch fir ,,	—	—	13.27	30.06	1.393	40.85	5 98	158.3
,, Hornbean ,,	12.5	28.3	—	—	—	—	—	—
,, Alder ,,	13.7	31.0	—	—	—	—	—	—
,, Larch ,,	—	—	—	—	1.408	41.25	6.04	160.0

II. CHARCOAL.

lbs. of Lead reduced by 1 lb. of Charcoal according to Berthier.			lbs. of Water heated from 0° to 100° C. by 1 lb. of Charcoal.	lbs. of Lead reduced by 1 lb. of Charcoal.	lbs. of Water heated from 0° to 100° C. by 1 lb. of Charcoal.	Air required for Perfect Combustion.
				Winkler.		
Commercial	Poplar charcoal	30.60	On an average 68	33.56	On an average 75.7	On an average 293.5 C. F. air at 19° C.
	Sycamore ,,	30.60		33.23		
	Ash ,,	29.60		33.23		
	Aspen ,,	29.5		—		
Enclosed in bottles immediately after being made	Fir ,,	32.3	On an average 72	33.51		
	Alder ,,	32.4		—		
	Birch ,,	31.4		33.71		
	Oak ,,	31.3		33.74		
	Beech ,,	—	—	33.57		
	Elm ,,	—	—	33.26		
	Lime-tree ,,	—	—	32.79		
	Willow ,,	—	—	33.49		
	Pine ,,	—	—	33.53		
	Scotch fir ,,	—	—	33.62		

III. PEAT.

Source of the Peat.	Berthier		Source of the Peat.	Winkler.	
	lbs. of Lead reduced by 1 lb. of Peat.	lbs. of Water heated from 0° to 100° C. by 1 lb. of Peat.		lbs. of Lead reduced by 1 lb. of Peat.	lbs. of Water heated from 0° to 100° C. by 1 lb. of Peat.
Peat from Troyes .	8.0	18.1	Among 24 sorts from the Hartz mountains, the worst gave .	11.9	26.9
,, Ham, dép. de la Somme .	12.3	27.9	,, ,, the best	18.8	42.6
,, Bassy, dép. de la Marne	13.0	29.2		Griffith.	
,, Framont, dép. des Vosges	15.4	34.9			
,, Ischoux, dép. des Landes	15.3	34.6	From Allen in Ireland . . .		
,, Königsbrunn, Wurtemberg	14.3	32.4	,, ,, upper	27.7	62.7
			,, ,, lower	25.0	56.6
			,, pressed peat	13.7	28.0

Karmarsch, in an extended examination of more than 100 varieties of Hanoverian peat, found a considerable difference among the individual kinds, which could not be definitely traced to their age or other properties; with reference to age, however, the following mean values were obtained:

1. Young peat.
   a. yellow grass peat evaporated per lb. 1.78 lbs. of water, and
   b. brown and black peat, 2.03 lbs. of water.
2. Old peat.
   a. earthy peat, 1.98 lbs., and
   b. pitch peat, 2.08 lbs. of water. In general, the quantity of water evaporated by 1 lb., ranged between 1.53 lbs. with the worst, and 2.27 lbs. with the best kinds.

IV. PEAT CHARCOAL.

Source.	Berthier.		Source.	Berthier.	
	lbs. of Lead reduced by 1 lb. of Charcoal.	lbs. of Water heated from 0° to 100° C. by 1 lb. of Charcoal.		lbs. of Lead reduced by 1 lb. of Charcoal.	lbs. of Water heated from 0° to 100° C. by 1 lb. of Charcoal.
Croutes-sur-Ourcq. départ. Seine et Marne . .	17.7	40.1	Essone, much used in Paris . .	22.4	50.7
Ham . . .	18.4	41.7	Framont, and peat from Champ du feu	26.0	58 9

The value of numerous other fuels as ascertained by this process will be found in the tables contained in the Appendix at the end of the volume.

One pound of peat requires for complete combustion, according to the determinations and analyses quoted above, from 70 to 134 cubic feet of air at 19° C. (66.2° F.); medium kinds require 149 cubic feet; 1 lb. of peat charcoal requires 155 to 228 cubic feet; 1 lb. of brown coal, according to the experiments with lead, requires 139 to 222 cubic feet, or 160 to 248 according to analysis; 1 lb. of coal requires by the lead test 170 to 279 cubic feet, average qualities 228 cubic feet, according to the analysis of Richardson from 248 to 303, according to Regnault, those from the coal formation require 320 to 332, those from the secondary formations 293 to 326 cubic

feet; 1 lb. of coke requires 194 to 250 cubic feet; 1 lb. of anthracite, according to the lead experiments, requires 233 to 277, according to Regnault's analysis 312 cubic feet. 1 cubic foot of air weighs 0.03794 lb. at the above temperature.

The numbers which have been cited, and which express the relative quantities of heat given off by different kinds of fuel, at first appear to be in direct contradiction to daily experience. The greatest quantity of heat, for instance, is obtained from the hard woods, whilst the experiments assign the first place to lime-wood and the softer species. The accurate analyses of Schödler and Petersen explain in a satisfactory manner the observations of practical experience; they show, that although pure woody fibre contains precisely the amount of hydrogen requisite for producing water with the oxygen, or the proportion of 1 of the former to 8 of the latter, yet the woods themselves contain a larger proportion, the excess of hydrogen varying in the different kinds. Thus the 44.5 parts of oxygen in oak-wood, require $\frac{44.5}{8} = 5.562$ parts of hydrogen to form water; the wood contains, however, 6.07 per cent., or $6.07 - 5.562 = 0.508$ per cent. more than is requisite to produce water, which is equivalent to 5.08 parts in 1000. In

V. BROWN COAL.

Locality.	Berthier.		Locality.	Berthier.	
	lbs. of Lead reduced from the Oxide by 1 lb. of Coal.	lbs. of Water heated from 0° to 100° C. by 1 lb. of Coal.		lbs. of Lead reduced from the Oxide by 1 lb. of Coal.	lbs. of Water heated from 0° to 100° C. by 1 lb. of Coal.
Gemeinde Dauphin, Basses Alpes	25.3	57.3	St. Lon, Basses Pyrénées	20.3	46.0
St. Martin de Vau', Canton de Vaud	22.6	51.2	Val-Pineau, dép. Sarthe	19.25	43.6
Minerme, dép. de l'Aude	22.8	51.6	Common German	18.40	41.7
Gardanne, Bouches du Rhône	22.0	49.8	Edon, dép. de la Charente	17.0	38.5
Fuveau	21.0	47.6	Alpheus, Greece	16.3	36.9
Enfant Dort	21.0	47.6	Triphillis „	16.3	36.9
Koep Fuarch, Lake of Zürich	20.7	46.9	Kumi „	15.8	38.8
			Elbogen, Bohemia	18 2	41.2
	Kühnert.			Regnault.	
Brown coal from Meissner	20.1	58.9	Earthy coal from Dax	21.38	62.6
Pitch coal from Meissner	15.9	46.6	„ from Bouches du Rhône	18.89	55.3
„ „ Ringkuhl	16.9	49.5	„ Lower Alps	16.69	48.9
„ „ Habichtswald	16.0	46.9	„ Greece	17.84	52.3
Glance coal from Ringkuhl	19.3	56.5	„ Cologne	18.24	53 4
Pitch coal from Habichtswald	19.0	43.6	„ Usnach	15.90	46.6
Lowest stratum, Ringkuhl	19.0	43.6		Varrentrapp.	
Mid. stra. Ringkuhl	10.0	43.9	Helmstedt, Prinz Wilhelm's mine	20.17	59.1
Stillberger coal	14.1	41.3	„ other mines	21 83	63.9
Lignite from Meissner	14.7	43.1	Schöningen, Gr. Treue	18.76	54.9
„ „ Laubauch	17.5	51.3	„ other mines	18.60	54.5

VI. MINERAL COAL.

Locality and Kind of Coal.	Berthier. lbs. of Lead reduced by 1 lb. of Coal.	Berthier. lbs. of Water heated from 0° to 100° C. by 1 lb. of Coal.	Berthier. lbs. of Water heated according to the Analyses, p. 53.
a. Caking coal.			
Coal from Dowlais, in Wales	31.8	72.0	—
Glamorgan	31.2	70.7	—
Eschwiller, near Aix-la-Chapelle	31.0	70.2	69.7
Lippe-Schaumburg	30.9	70.0	80.0
Newcastle	30.9	70.0	71.5
Carmeau, near Alby	30.1	68.2	—
Rive de Gier, Grand Croix	29.6	67.0	78.0
Mons, Bouleau-Fontaine-Madame	29.0	65.7	—
Cannel coal, Wigan	28.3	64.1	76.0
Mons, Grand-Gaillet	28.1	63.6	—
Rochebelle, near Alais	27.6	62.5	79.7
Mons, nouvelle Alliance pit	27.4	62.1	—
Bonchamp, Haute Saône	27.3	61.8	—
Bessèges, Aveyron	27.0	61.1	—
St. Pierre la Cour, near Mayenne	27.0	61.1	—
Epinac, Saône et Loire	26.8	60 7	72.8
From Oviedo, in Asturia	26.1	59.1	—
Treuil mine, near St. Etienne	25.4	57.5	—
Bellestat, Aude, called jet	24.4	55.2	—
Jet (locality unknown)	23 3	52.8	—
b. Sinter coal.			
Cherry coal, Derbyshire	27.2	61.6	—
Soft coal ,,	26.3	59.5	—
Oviedo, in Asturia	26.1	59.1	—
Cannel coal, from Glasgow	24.9	56.4	—
St. Georges di Lavencas, Aveyron	24.0	54.5	—
Cannel coal from Lancashire	23.5	53.2	—
Ombrowa, Silesia	21.2	48.0	—
Salin, Jura	21.0	47.5	—
Vazas, Slavonia	19.4	43.9	—
c. Sand coal.			
Durham	31.6	71.6	—
Rolduc, near Aix-la-Chapelle	31.0	70.2	80
Zinsweyer, near Offenburg	22.2	50.3	—

VII. COKE.

Species of Coke.	Berthier. lbs. of Lead reduced by 1 lb. of Coke.	Berthier. lbs. of Water heated from 0° to 100° C by 1 lb. of Coke.
A la Garre, from coal of St. Etienne	28.5	65.6
From coal of Bessèges	28.4	64.3
,, Rive de Gier	26.0	58.9
Gas coke from Paris	22.2	50.3

VIII. ANTHRACITE.

Locality.	Berthier. lbs. of Lead reduced by 1 lb. of Anthracite.	Berthier. lbs. of Water heated from 0° to 100° by 1 lb. of Anthracite.	Berthier. lbs. of Water heated according to Analysis.
Anthracite from Lamure, near Grenoble	31.6	71.5	72.8
From Pennsylvania	30.5	69.1	75.6
From Laval (la Chaumière	33.0	74.7	—
From Laval (la Baconière	26.6	60.2	—
From Corbattière, in Savoy	26.7	60.5	—

like manner, we find hydrogen in excess in the following woods, in 1000 parts:

Excess of Hydrogen.		Excess of Hydrogen.		Excess of Hydrogen.		Excess of Hydrogen.	
Oak-wood	5.08	Birch	7.50	Lime-wood	13.90	Pine-wood	8.80
Ash	5.05	Elm	10.00	Willow	7.00	Scotch-fir	7.70
Maple	8.30	Poplar-wood	8.20	Deal	9.50	Larch	8.60
Beech-wood	6.50						

This excess of hydrogen will give rise to the formation of gaseous hydrocarbons when the wood is heated, thus removing a considerable portion of carbon and proportionally diminishing the residual charcoal. It is principally these gases and vapours which burn so readily, and produce the flame. The lighter kinds of wood are, therefore, characterized chemically by a larger excess of hydrogen, which causes the first stage of their combustion (*combustion with flame*) to be augmented at the expense of the second—the *incandescence of the charcoal;* they consequently burn with greater facility or *evolve their heat in a shorter space of time* than the hard woods. This property may very properly be called that of *greater combustibility*, and the heat given out must necessarily be greater, as hydrogen requires more oxygen for perfect combustion than carbon, and evolves considerably more heat. Our arrangements for applying heat, however, are generally of such a nature as to require time for the communication of the heat evolved by the fuel. If the evolution is too rapid, the necessary time is not allowed, and much heat escapes without serving any useful purpose. Hard woods are therefore prepared for most purposes, because the softer kinds evolve the quantity of heat they are capable of producing in such a manner as to be useless in the furnace, and not from any actual deficiency in their heating power. Whenever a very intense heat is required, as, for example, in the porcelain kilns, the preference is given to the soft woods. These remarks are equally applicable to other kinds of fuel.

The time required for combustion, and consequently for the evolution of heat, is also dependent on the state of division of the fuel. A certain weight of wood, for example, in the form of shavings, comes much more rapidly in contact with the air than when in the form of a single compact piece. In the former case, many more portions of the wood will burn simultaneously than in the latter, and the evolution of heat will cease in a comparatively short space of time. While the compact log is slowly consumed, and is capable of keeping the surrounding parts (the sides of the furnace) at a moderate temperature for hours, the shavings will bring it to a red heat, although only for a few minutes. This circumstance is of great importance in practice, and accounts for the preference given to the Newcastle steam coal over the Welsh. The combustibility of the fuel, however, or the quantity which is consumed within a given time, is not increased by too great a subdivision, which leads to a directly opposite result, and ultimately, if carried to an extreme, renders the fuel absolutely incombustible. Charcoal powder, sawdust, crushed coal of the best quality, powdered peat, &c., cease to be combustible bodies, if an ordinary form of grate is used, as the small particles lie so closely together that they prevent access of air. They are consequently valueless, unless the surface of the grates can be covered with blocks of sandstone, limestone, or some similar material, so as to prevent the powder from falling through the grate, and yet allow access of air, as formerly practised in some boiler-fires and glass furnaces in the neighbourhood of Newcastle upon-Tyne, or unless burned or made into gas in special appliances.

Fuel in this finely divided state has been rendered available, also, by

various mechanical contrivances, fully described under Patent Fuel; in this state it appears to offer some advantages over the raw material, compensating, under certain circumstances, for its higher price. Thus the carboleine of Weschnaekoff, as well as the other patent fuels, although considerably more costly than coal, may, from their superior heating power and small bulk, be employed with advantage in steam navigation. As an example, we may suppose a steamer of 1,000 horse-power, requiring for one journey 81,884 cubic feet (2,240 tons) of coal; now, according to the observations which have been made, 0.643 parts of carboleine will do the work of 1 part of coal, while in addition the relative volumes of equal weights are as 0.98 to 1. Sixty-three cubic feet of carboleine will therefore effect as much as 100 cubic feet of coal, or 51,587 cubic feet will be sufficient for one journey, leaving (81,884 – 51,587) about 30,000 cubic feet of the ship's space unoccupied. If the freight be calculated per cubic foot, and each cubic foot is charged at the rate of 5*s*., there will be a saving of about £6,959, after deducting £641 as the extra price of the carboleine.

The above experimental results exhibit the comparative quantities of heat which can possibly be obtained from fuel, expressed in quantities of water raised by its means from 0° to 100° C. in temperature; they therefore express the greatest possible amount of heat which these can produce. If the amount of heat actually obtained in practice, and made available in the arts and manufactures, be compared with this, it will be found exceedingly small. A considerable portion of the heat, therefore, which the fuel is capable of generating by its combustion, is either not evolved in practice, or is lost by the mode of application. Both cases occur; but in order to discover the sources of this loss, it will be necessary to examine the principles on which the application of heat depends.

ON FLAME.

The nature and propagation of flame are intimately connected with the application of fuel, and the subject, if understood, bears directly on that of the intensity of the heat which we produce by combustion.

Nature of Flame.—What is flame? Dr. Mills has remarked that a flame may be regarded as volatile matter undergoing chemical change at a visibly red heat; and Dr. Percy, with more minuteness, says: "Ordinary flame is gas or vapour of which the *surface*, in contact with atmospheric air, is burning with the emission of light."

These definitions leave little to be desired, as they properly direct attention to *visibility* rather than to temperature, and to the fact that the presence of combustible *gas* or *vapour* is a necessary condition to the existence of flame. We may have a solid, such as iron, magnesium, or carbon,* burning in oxygen or air, at a high temperature, with brilliant incandescence, or glowing, but without flame, whilst, on the other hand, the flame of boric methide shows that flame may exist without a high temperature.

Flames are usually regarded as simple or compound according to the number of products which result from them. Those which are ordinarily used in the arts and manufactures are compound flames.

From the foregoing definition of flame, it will be readily understood that all flames are more or less hollow in structure. In the centre is a space occupied by unconsumed gases; surrounding, that is, the luminous portion of the flame; and outside of all is the non-luminous part, or "mantle," as it is called. The unconsumed inflammable gases can be collected from the centre

* This is true of single pieces of carbon—a mass of carbon burning in air or oxygen generally shows a lambent blue flame on the surface, which is due to the burning of carbonic oxide, CO, formed by the reduction of the carbonic anhydride, CO_2, in its passage through the glowing carbon.

of the flame and afterwards ignited, and the mantle can be rendered more visible (according to Bloxam*) by burning sodium near the flame, when the mantle will acquire a strong yellow tinge.

In a blow-pipe flame, the same construction is observed, the flame, however, being diminished in size and luminosity; but by mixing air with gas before ignition, the three portions of a flame are reduced to two, with a considerable reduction in the luminosity of the flame. The combustion becomes complete at an earlier period, and the luminous cone has the same character as the mantle in the former case.

Temperature and Propagation of Flame.—Some interesting observations made by Deville† on the flame of carbonic oxide burned with oxygen show the chemical composition of the gases at various parts of the flame. He found that when a mixture of carbonic oxide and oxygen in the combining proportions (2 vols. CO to 1 vol. O) was allowed to issue, under a slight pressure, from a jet having an area of 5 square millim., a flame of 70 to 100 mm. high was formed, consisting of an inner and an outer cone. The outer cone, in which combustion takes place, was deep blue at the base and yellowish or nearly colourless towards the apex. In the inner cone, which was only 10 mm. high, no combustion took place, because the rapidity of displacement of the particles of gas was there superior to the very slow rate of propagation of heat in the mixture.

To collect the gases from the different parts of the flame, a silver tube, pierced with a small aperture, was placed across it in the part to be examined, and the gases were aspirated by passing a rapid stream of water through the tube. They were thus quickly cooled, and, passing along the tube together with the water, were collected, by means of a bent delivery tube, in jars over water.

The following table gives the results of the various observations, the first column giving the positions of the silver tube above the orifice from which the gases issued, the second column the temperatures approximately at these points, and the last division of the table the composition of the gas at the different portions of the flame:—

Height above Orifice.	Corresponding Temperatures.	Composition of the Gas.		
		CO	O	CO_2
67 mm.	Melting heat of silver, and above	0.2	21.3	78.5
54	Melting heat of gold	6.2	28.1	65.7
44	Commencing white heat of platinum	10.0	20.0	70.0
35	White heat of platinum	17.3	24.8	57.9
28	Strong white heat of platinum	19.4	26.5	54.1
18	Intense white heat of platinum	29.0	25.1	45.9
15	Incipient fusion of platinum	40.0	32.9	27.1
12	Melting point of platinum	47.0	36.0	17.0
(1) 10	Sparkling of the melted platinum	55.3	35.3	9.4
(2) 10	Still higher temperature	55.1	36.5	8.4
(3) 0		64.4	33.3	2.3

(1) A litle above the apex of the inner cone.
(2) Somewhat below the apex of the inner cone.
(3) Original mixture.

These numbers show that the highest temperature is at the apex of the inner cone or a little below it; that the temperature gradually diminishes towards the apex of the flame; and that the quantity of carbonic anhydride increases in the same proportion from the apex of the inner cone, where, at most, $\frac{2}{3}$rds of the carbonic oxide and oxygen enter into combination, to the

* "Chemistry," edition 1867, p. 95.
† "Bull. Soc. Chim." [2], v. 111; also Watts, "Dict. of Chemistry."

vertex of the flame itself, where carbonic oxide can no longer be detected. At the apex and edges of the inner cone, the carbonic oxide and oxygen unite almost instantaneously, but only partially, on account of the very high temperature there existing.* Bunsen also carefully investigated this subject, and introduced† some modifications of the views held previously. Watts (Dict. of Chem., i. 860, Affinity) has summarized this matter as follows:—When a combustible gas mixed with oxygen is set on fire, a rise of temperature takes place, which, supposing the combustion to be perfect, may be calculated from the heat of combustion of the gases and the specific heat of the products. If, on the other hand, the combustion is imperfect, the temperature may still be calculated with the aid of Mariotte's and Gay Lussac's laws, provided the pressure exerted by the gaseous mixture when exploded in a closed vessel be known. This pressure has been determined by Bunsen for mixtures of hydrogen and carbonic oxide with oxygen, or with oxygen and nitrogen together, by means of a eudiometer having a loaded safety valve. From this and the observed temperature of combustion, the quantity of the combustible gas (carbonic oxide or hydrogen) which has been burnt at the moment when the flame attains its maximum temperature, and thence also the quantity which at this temperature has lost its power of combining, may be calculated.

The following table contains the results of Bunsen's experiments arranged according to the maxima of temperature ($t'-t$) which the several gaseous mixtures, calculated for volumes at 0° C., attain by combustion in a closed vessel. Columns I. and II. give the mixtures of gases used; $\frac{P}{P_o}$ = the pressure produced in atmospheres by explosion; t = the calculated temperatures; and k = the calculated proportion of combination.

No.	Mixtures of Gases. I.	with	II.	$\frac{P}{P_o}$ III.	t IV.	k V.	Mean.	Deviation from Mean
1	2 vol. CO + 1	vol. O		10.78	3172°	0.351		+0.0194
2	„ CO + 1	„ O		11.19	2893	0.319		−0.0126
3	„ H + 1	„ O		9.97	2854	0.338	0.3316	+0.0064
4	„ H + 1	„ O		9.75	2833	0.336		+0.0044
5	„ CO + 1	„ O + 0.1079	vol. O	9.05	2558	0.314		−0.0176
6	„ CO + 1	„ O + 0.6857	„ CO	8.89	2471	0.460		−0.0421
7	„ CO + 1	„ O + 0.8854	„ O	8.44	2325	0.478		−0.0241
8	„ CO + 1	„ O + 1.0861	„ O	7.86	2117	0.490		−0.0121
9	„ CO + 1	„ O + 1.2563	„ N	7.73	2084	0.515		+0.0129
10	„ H + 1	„ O + 1.2599	„ N	7.49	2024	0.547	0.5021	+0.0449
11	„ CO + 1	„ O + 1.2563	„ N	7.35	1909	0.470		−0.0321
12	„ CO + 1	„ O + 1.7145	„ O	6.67	1726	0 520		+0.0179
13	„ CO + 1	„ O + 2.1559	vols. O	5.83	1460	0.512		+0.0099
14	„ CO + 1	„ O + 3.1629	„ CO	4.79	1146	0.527		+0.0249

These numbers, in Bunsen's view, show that, in a mixture of carbonic oxide or hydrogen with the exact proportion of oxygen required for combustion, and unmixed with any diluent gas, only $\frac{1}{3}$rd of the carbonic oxide or hydrogen is burnt at the maximum temperature, whilst the other $\frac{2}{3}$rds, by being raised to the high temperatures of 2558° to 3033°, have lost the power of combining; moreover, that, when 1 volume of the same mixture is diluted with 0.686 to 3.163 volumes of any gas that does not burn with it, and the temperature of the flame is successively reduced thereby from 2471°

* See also Thorpe on the Theory of the Bunsen Lamp, "Jour. Chem. Soc.," 1877, i. p. 627, for Blochmann's investigations, or "Annalen Chem. Pharm.," vol. clxviii. p. 295.

† "Phil. Mag.," vol. xxxiv. p. 489, and "Gasometry," by R. Bunsen.

to 1146°, then, at all temperatures within these, exactly half of the carbonic oxide or hydrogen is burnt, the other half having lost the power of combining.

From this it has been inferred that the combustion of gases takes place in a manner different from that which had been previously supposed. When a mixture of 2 volumes of carbonic oxide with 1 volume of oxygen is set on fire, and its temperature thereby raised from 0° to 3033° C., two-thirds of the carbonic oxide remains in an unburnt, and for the time incombustible, state. The temperature is then lowered by radiation and conduction from 3033° to 2558° without any combustion of the carbonic oxide, but when the temperature falls somewhat lower, combustion recommences, restoring the heat lost by radiation and conduction, and raising the temperature again to 2558°, but not above that point. The gradual fall of temperature from 3033° is followed by a continuance of the temperature 2558° till exactly half the carbonic oxide is burnt, whereupon a third phase sets in, during which, again, no combustion takes place until the inflamed gaseous mixture has cooled down to at least 1146°. As, however, the gaseous mixture, after cooling, consists almost wholly of carbonic anhydride, these alternate phases of constant and decreasing temperature must be repeated below 1146° until the last portion of the gas is burnt. This discontinuous combustion of a uniform mixture of a combustible gas with oxygen is referred by Bunsen to a law of combination established by him.

These facts, as observed by Bunsen, are of great importance in connection with the inflammation of gases, although it is probable, as Berthelot has indicated, that Bunsen's temperatures are too high in consequence of his not having considered the contraction of volume due to combination.

Berthelot* announced that the combustion temperatures in Bunsen's experiments may be anything between the limits shown in the following numbers, keeping the same numerical order as in the foregoing table:—

No.	t^1	t^2	No.	t^1	t^2
1	4140°	2612°	8	2280°	1875°
2	3900	2537	9	2203	1838
3	3809	2449	10	2126	1715
4	3718	2389	11	2083	1734
5	3066	2198	12	1875	1548
6	2760	2154	13	1505	1319
7	2537	2031	14	1150	1034

A number of experiments on this subject have been made since Berthelot's criticism appeared, but the conclusions arrived at are contradictory. All, however, agree in observing a great absorption of heat at high temperatures, which is thought to be due either to a change in the specific heat of gases or to dissociation. Messrs. Berthelot and Vieille† and Mallard and Le Chatelier‡ have advanced and supported the former view, while the latter has been advocated by Mr. Dugald Clerk§ and Prof. Rücker of Leeds. It is probable that both causes operate to produce the phenomena which have been observed.

The rate of ignition of gaseous mixtures is also a point of considerable importance. Sir H. Davy‖ propounded a theory of this action, but it does not seem to be entirely supported by more recent investigations.

* *Ann. de Chim. et Phys.*, [5] vol. xii. pp. 302–310; "Jour. Chem. Soc.," vol. xxxiv. p. 5; *Compt. Rend.*, vol. lxxxiv. (1877), p. 407.

† *Essai de Mécanique Chimique*, Paris, 1879; *Ann. de Chim. et de Phys.*, 5me ser. xxvii. and xxviii.; 6me ser. iv. pp. 13–84.

‡ *Compt. Rend.*, 1880, 1881, vols. xci., xciii.; *Annales des Mines*, 8me ser. *Memoires*, iv. p. 274.

§ On the Theory of the Gas Engine, "Min. Proc. Inst. C.E," vol. lxix. part iii.; also *ibid.* vol. lxxxv pp. 1–53. See also Rossetti, On the Temperatures of Flames, "Jour. Chem. Soc.," vol. xxxiv. pp. 467, 694. &c.

‖ "Researches on Flame." See also Watts, Dict. of Chem., "Combustion." i. 1089.

Bunsen found that the velocity of the propagation of combustion in a pure detonating mixture of hydrogen and oxygen was 34 mètres per second, and in a maximum explosive mixture of carbonic oxide and oxygen it was less than 1 mètre per second. When the explosive gases are gradually diluted with a gas that does not take part in the combustion, the rate is lowered, and it can be brought down thus until the progress of combustion is made visible to the eye.

Bunsen's method of determining these velocities is thus described by Dugald Clerk (*loc. cit.*):—The explosive mixture was allowed to burn from a fine orifice of known diameter, and the rate of the current of the gaseous mixture was carefully regulated by diminishing the pressure to the point at which flame passed back through the orifice and ignited the gases below it. This passing back of the flame occurs when the velocity with which the gaseous mixture issues from the orifice is inappreciably less than the velocity with which the inflammation of the upper layers of burning gas is propagated to the lower and unignited layers.

Professor Mallard,* of the Ecole des Mines, made a series of observations by this method on the rate of the propagation of combustion in mixtures of coal gas and air, and of marsh gas and air. In the latter mixtures, the maximum rapidity of inflammation was found to be about 0.56 mètre, or rather more than half a yard, per second. This velocity was attained with a mixture of 1 vol. marsh gas and 8½ vols. air. When the proportion of air was increased to 12 vols. or diminished to 5.9 vols., the mixture was neither explosive nor inflammable.† Prof. Thorpe remarks on this that it is worthy of note that the proportion of air corresponding with the maximum rate of inflammation is less than that which contains oxygen sufficient for the complete combustion of the marsh gas. This, however, is what the observations by Bunsen and others, previously quoted, would lead us to expect.

The maximum rapidity of inflammation in mixtures of coal gas and air was attained with a mixture of 5 volumes of air and 1 volume of coal gas, and was 1.02 mètre, or rather more than 1 yard, per second. One volume of coal gas with 6½ vols. of air gave a rate of 0.285 mètre, or 11 inches, per second. The rate was very rapidly diminished by an excess of either constituent; a mixture containing more than 8 vols. and less than 3½ vols. of air to 1 of coal gas was found to be uninflammable in the way described.‡

Dugald Clerk has pointed out that these are the rates of ignition at constant pressure, and that in a closed space the conditions of inflammation are quite different in consequence of the expansion of the ignited portion and mechanical disturbance of the remaining part of the gaseous mixture. Experiments are needed to determine the rate of ignition for constant volume. Some remarkable results are given by this author, which were obtained by so arranging the plan of ignition that a small volume of gases was first ignited, which expanded and projected a flame through a passage into the mass of an inflammable mixture, thus adding to the rate of ignition the mechanical disturbance produced by the entering flame. He succeeded by this means in producing maximum pressure (or maximum ignition) in $\frac{1}{100}$th part of a second in a space containing 200 cubic inches of gas. By firing a mixture with varying amounts of mechanical disturbance, almost any time of ignition could be obtained between $\frac{1}{100}$th and $\frac{1}{10}$th of a second. It did not matter whether the mixture used was rich or weak in gas; the rich mixture could

* *Annales des Mines*, vol. vii. 1875, p. 355. Thorpe, On the Theory of the Bunsen Lamp, "Jour. Chem. Soc.," 1877, i. p. 631.

† See also Coquillion's results in "Jour. Chem. Soc.," 18[illegible], i. p. 166, and in *Compt. Rend.*, 1876, vol. xxxiii. p. 709.

‡ *Compt. Rend.*, vol. xcv. pp. 151–157; *Ann. de Chim. et Phys.*, [6] vol. vi. 1885, pp. 546, 556.

be fired slowly, and the weak one rapidly, just as was required. He found that the rate of ignition of the strongest possible mixture is so slow that the time of attaining complete inflammation depends on the amount of mechanical disturbance permitted.

Mr. Lewis T. Wright has recorded* some interesting observations on the velocity of the propagation of flame, and has announced that, when flame travels at a greater velocity than 4¼ feet per second, it will pass through the gauze used in safety lamps. He also found that a flame of low velocity in a confined space may become so much agitated by an increase in its own oscillations as to cause the introduction of a very rapid rate of ignition in the remaining portions of the gaseous mixture. He remarks that "a definite explosive mixture may have a velocity of propagation of flame, when it is undergoing explosion of the first order, as low as 1½ foot per second; but when it becomes sufficiently agitated to give an explosion of the second order, the rate of propagation of flame is several thousand feet per second."

The following table shows the results of experiments with various mixtures of gases, giving the rate at which an explosion of the first order (that is, a slow ignition) travels with each mixture in a glass tube 13 feet long and 0.75 inch diameter:—

Mixtures.		Lineal Velocity of Efflux of Mixture.	Rate at which Explosion of First Order travels in Tube.	Total Velocity of Propagation of Flame.
Gas.	Air.	Feet per Second.	Feet per Second.	Feet per Second.
10.3 %	89.7 %	1.21	1.1	2.31
12.2	87.8	1.24	2.0	3.24
15.0	85.0	1.28	3.0	4.28
17.7	82.3	1.32	4.8	6.12
19.6	80.4	1.35	3.0	4.35
21.2	78.8	1.38	2.4	3 78
22.1	77.9	1.39	1.3	2.69
23.0	77.0	1.41	Stationary	—

Wright also found that, whenever an explosion is produced inside a safety lamp having ordinary gauze, the flame was projected through the gauze, and could ignite gas at a considerable distance from the lamp. By employing stiff wires for the woof and lighter wires for the warp, he produced a "basket-work" gauze having small tortuous openings and a relatively large weight of metal, which did not allow flame from an explosion to pass through.

Luminosity of Flames.—According to the commonly received theory of the causes of luminosity in flames (first propounded by Sir H. Davy†), the presence of solid particles suspended in the flame (or in immediate contact with the burning gas) is essential to its luminosity.

There is no doubt that the introduction of solid particles in a fine state of division into a flame of feeble luminosity will impart to it a considerable degree of brilliancy by the incandescence of the solid particles, or perhaps in some cases by reflection of the light from their many surfaces. No sound conclusion, however, as to the luminosity of flames in general can be drawn from such an analogy as is afforded by the result of such an experiment, because Tyndall has shown that the same result is produced when the solid introduced is one that does not burn. The presence of solid particles, according to the common idea, in luminous flames is only assumed, not

* "Jour. Soc. Chem. Ind.," vol. vi. pp. 362-364.
† "Phil. Trans." for 1817, p. 75.

proved. It is usual, however, to refer to the black deposit which is formed upon a glass rod or similar body, when it is held in the flame of a candle or of hydrocarbon gas, as a proof that such flames contain solid particles. This, however, is not a conclusive proof, for Dr. Frankland* has pointed out that this deposit is not pure carbon, but is a hydrocarbon compound. To this Dr. Percy† objects that it is fixed, not volatile, whatever its composition may be; but the objection seems to be irrelevant, because it refers to the substance as deposited, and we do not know that such a substance existed in the flame. The introduction of the cold surface of the glass rod not only condenses some vaporous hydrocarbon, but doubtless also causes decomposition of some of the many hydrocarbons which make their appearance in the gradual resolution of carbonaceous matter. As, therefore, we do not know in what combination this substance producing the black deposit existed while it was originally in the burning gas, it cannot properly be asserted that it was "fixed, not volatile."

The phenomena of many luminous flames are explained by various writers, with more or less ingenuity, on the hypothesis of solid particles, but the experiments and observations of Dr. Frankland‡ have shown that that hypothesis is not wholly satisfactory, because luminous effects have been produced where it could not account for them, such, for example, as the luminosity of the flame of hydrogen burning in oxygen under pressure, and, secondly, because in many of the brightest flames the temperature is such that fuliginous matter§ could not exist in them. In many cases, it might seem, therefore, to be a more satisfactory explanation, that the luminosity of flames depends on the existence of a comparatively high temperature, and on the presence of gases or vapours of considerable density.‖ ¶

The effect of high temperature is seen in the greater brightness of the flames of sulphur, phosphorus, and, indeed, all substances when burnt in pure oxygen, as compared with the result of their combustion in air. Direct evidence of the effect of high temperature is also afforded by the combustion of phosphorus in chlorine, for, whilst at ordinary temperatures only a feeble light is produced by this combustion (although the product PCl_3 has considerable density), strongly heated phosphorus vapour burns in hot chlorine with a dazzling white light.

A comparison of the relative densities of gases and vapours shows that the brightest flames in general are those which contain the densest vapours.

* "Proc. Roy. Soc. Lond.," vol. xvi. 1868; "Phil. Mag.," vol. xxxvi. 1868, pp. 309–311; "Experimental Researches;" "Lectures on Coal Gas."

† "Metallurgy," vol. "Fuel," p. 158.

‡ *Op. cit.*, and "Jour. Chem. Soc. Lond.," 1864. vol. xvii. pp. 52–55; "Brit. Assoc. Reports," vol. xxxviii. p. 37; "Proc. Roy. Instit.," vol. v. 1869, pp 419–423; "Proc. Roy. Soc. Lond.," vol. xxx. No. 201.

§ See lectures on Coal Gas, delivered at the Royal Institution, London, March 1867, by Dr. Frankland, published in "Jour. of Gas Lighting," &c., London.

‖ "Jour. Soc. Chem.," 1862, vol. xv. p. 168; Watts, "Dict. of Chemistry," 1st sup., p. 485.

¶ [Although it may be that in exceptional cases the luminosity of a flame is due to incandescent vapour, it would be incorrect to suppose that this is invariably true of the luminous flames produced by the combustion of hydrocarbons and other carbon compounds. Soret's experiments (Phil. Mag. 1875, p. 50), recently extended and confirmed by Burch (Nature, vol. xxxi. p. 272), would seem to prove incontestably that the luminosity of a candle flame at all events is due to intensely ignited solid matter. It was found that when the image of the sun was thrown by means of a lens on to the flame of a candle, a spot of light appeared, and this light, on examination by a spectroscope, showed all the Fraunhofer lines distinctly. Moreover, when examined by means of a Nicol's prism, the light was found to be completely polarized at right angles to the line of incidence, proving that it was reflected from solid particles. We can scarcely doubt that the luminous flames of hydrocarbons, &c., when examined will give precisely similar results.—EDITOR.]

RELATIVE DENSITIES OF SOME GASES AND VAPOURS.

Hydrogen	1	Oxygen	16
Water	9	Carbon dioxide	22
Hydrochloric acid	18¼	Sulphur dioxide	32
Arsenious chloride	93¾	Phosphoric oxide	71 or 142
Metallic arsenic	150	Chlorine	35·5
Arsenious oxide	198	Mercury	200
Air	14·5		

Hydrogen burning in chlorine produces a vapour more than twice as heavy as that resulting from its combustion in oxygen, and accordingly the light produced in the former case is stronger than in the latter. Carbon and sulphur burning in oxygen produce vapours of still greater density (viz., CO_2 and SO_2), and their combustion gives a still brighter light. Phosphorus, also, which has a very dense vapour, and yields, in burning, a product of great vapour density, burns in oxygen with a brilliancy almost blinding.

The luminosity of a flame is increased by compressing around it the surrounding gaseous atmosphere, and is diminished by rarefying it. Thus, mixtures of hydrogen and carbonic oxide with oxygen emit but little light when they are burnt or exploded in free air, but exhibit intense luminosity when exploded in closed vessels so as to prevent expansion of the gases at the moment of combustion.

Frankland experimented with jets of hydrogen and carbonic oxide burning in oxygen under a pressure which he gradually increased to twenty atmospheres, and obtained brilliant luminous effects, including bright and continuous spectra. Even the faint flame of alcohol, as in an ordinary spirit lamp, becomes highly luminous under the receiver of a condensing pump, when the pressure of air is increased to 120 inches of mercury.

We are indebted to Frankland* also for the observation that the diminution in illuminating power is directly proportional to the diminution in pressure; and, as applied to ordinary domestic gas-burners, this means that, as the barometer falls, the light from them diminishes at the rate of 5.1 per cent. for every inch of fall. According to Dr. Letheby,† "in London the difference in the value of the light when the barometer is 31, as compared with what it is at 28, is fully 25 per cent."

The flame of arsenic burning in oxygen may also be rendered quite feeble by rarefying the oxygen; and, at high altitudes, flames exhibit the effects of rarefied air. Tyndall and Frankland‡ made observations on the combustion of stearin candles at the summit of Mont Blanc and at Chamouni, and found a considerable decrease in luminosity at the high elevation, although the rate of combustion of the candles remained the same in both places. The energy of combustion was therefore unaltered, although the flame in one case had a higher temperature than in the other, resulting from the increased density of the gaseous atmosphere. Percy shows (vol. "Fuel," p. 159) that this conclusion should be drawn even from the theory propounded by Tyndall in explanation of the diminished luminosity which he observed on Mont Blanc. Tyndall's theory was, that the decrease in luminosity was mainly due to the greater mobility of the air. From this Percy reasons, "Now, if increased mobility of the air be caused by rarefaction, the opposite should result from compression, in which case the movement of the particles would become sluggish, intermixture of the air and flame-producing gas would be less rapid, and the diffusion of the gaseous products of combustion in the surrounding air would be retarded, with consequent increase of temperature."

* *Op. cit.*, and "Phil. Trans.," vol. cli. 1861. p. 629.
† "Common Sense for Gas Users," by R. Wilson, p. 19 (London: Crosby Lockwood & Co.).
‡ "Heat Considered as a Mode of Motion," by J. Tyndall, F.R.S., 1865, p. 50.

Frankland's conclusions have also been confirmed by some experiments made by Prof. V. Wartha* on the influence of pressure on flames.

ON THE APPLICATION OF FUEL.

Prevention of Smoke.—In the practical application of fuel, the most pressing question in these days is how best to use it for domestic and industrial purposes while securing abatement of the smoke nuisance. There is a considerable amount of difference between the conditions as to the supply of fuel under which this problem must be worked out for domestic purposes and those involved in its relation to industrial operations. For this reason, these really constitute two branches of the subject, which must be considered to some extent apart.

The prevention of smoke, or even the abatement of the smoke nuisance in towns, depends on the degree of completeness of combustion which is secured, and it is not impossible to secure the fullest degree even with the use of fuels which have a greater tendency to burn with smoke than others have. For instance, although, with ordinary appliances, methane or marsh gas burns without smoke, yet it has been made to produce smoke in burning by limiting the air supply (see Lewis T. Wright, Jour. Chem. Soc. Trans. 1885, pp. 201-2); and, on the other hand, a naturally smoky fuel, like benzene vapour, can be made to burn without smoke by mixing it with air previous to ignition.† Wax, stearin, and olein are less liable to burn with smoke than paraffin, because of the amount of oxygen which they contain, and that in spite of their larger proportion of carbon. A good practical illustration of the conditions affecting the presence or absence of smoke in combustion is afforded by the argand gas-lamp for ordinary illuminating gas. When this gas is burned in the lamp without a glass chimney, a long smoky flame is produced; but as soon as a chimney is applied the flame is shortened, rendered brighter, and free from tendency to smoke under almost any conditions of the surrounding atmosphere. The effect of the chimney is, as is well known, to induce a better distribution and a more intimate contact with the flame of the air supply, which is also partially heated, and thus rendered effectual in producing a higher temperature of combustion.

The great requisites for perfect combustion are—(1) intimate mixture and contact between the particles of the combustible and the air, and not mere access of even an unlimited supply of air, and (2) the maintenance of the most suitable temperature for the chemical combinations involved during the whole period of the combustion. Where these are secured, whether in domestic or in industrial appliances, the best results are obtained from the fuel, and the production of smoke is prevented. In using solid fuel, however, it is practically impossible to ensure the accomplishment of all these conditions, as only the surface of the solid can be in contact with the air. Moreover, in order to secure the maintenance of a sufficiently high temperature to ensure combustion, one part of the fuel must be burned to carbonic acid, and this gas, passing through other portions of the fuel, unites with more carbon, and is reduced to carbonic oxide, which, if hot enough, when brought into contact with air, ignites, and burns to carbonic acid again.

It will be understood that different and varying quantities of air are required for these different operations, and, as in the majority of instances it is impossible to regulate this supply in any adequate manner, the use of solid fuel is consequently subject to loss from various causes; these include the dilution and cooling of the carbonic oxide produced, so that some of it passes off unconsumed when an excess of air is admitted, or a similar result in loss

* *Jour. für Gasbeleuchtung*, vol. xix. p. 761; "Min. Proc. Inst. C.E.," vol. xlviii. part ii. p. 329.

† See Bloxam's "Chemistry," pp. 97, 98, edition 1867.

of carbonic oxide when the air supply is insufficient, the formation of smoke, &c. The thermal results produced by the use of solid fuel are also unsatisfactory in view of that which is theoretically attainable supposing perfect combustion and the absence of any excess of air; further, the requirements of the operation of charging fresh quantities of fuel periodically, and the removal of ash and cinders in a heated state, also constitute sources of loss of heat. Calculations of these losses are given in several works, including Rankine's Steam Engine, &c., Box's Treatise on Heat, Galloway's Fuel, &c., Schwackhofer and Browne's Fuel and Water, &c. The use of liquid fuel to a great extent obviates these various sources of loss, but this form of fuel can at present be considered as suitable only for industrial purposes, its economical application depending on its price and the quantity available for a regular supply. The use of gas fuel derived from the decomposition of coal (or even from that of liquid fuel) affords the best conditions for the complete control of the operations of combustion and for the useful realization of a large proportion of the heat developed thereby. The most intimate contact between the particles of the combustible and of the air can be secured, along with thorough control both of the quantities of each and of the rate of ignition, and consequently of the temperature produced and maintained. The sources of loss which are incident to the use of solid fuel are eliminated, and the degree of temperature which may be produced by the combustion of carbonic oxide with air has been shown* to be greater than that produced by the combustion of solid carbon, although the theoretical thermal equivalent of carbon is 8,080, and that of carbonic oxide only 2,403. This result is due to the smaller quantity of air required for combustion, and the consequent less diminution of the heat by nitrogen and carbonic acid.

Having arrived at this point, the question arises, Is it advantageous to use coke instead of gas for any purpose? It is certain that gas can be used more efficiently and economically for any purpose to which coke can be applied, except in the blast furnace and in some rare instance of a special appliance or of a chemical furnace where the combustion-chamber space is circumscribed, or the atmosphere in the furnace is inimical to combustion; but as coke is at present produced, it follows that some use must be found for it in heating operations, or some method must be devised of avoiding its production even in gas making.

Coke fires have the advantage of being smokeless, but when introduced for domestic purposes they have the disadvantage that, when the temperature falls to a considerable extent, the carbonic acid produced may be delivered into the atmosphere of the room instead of being removed by the chimney; moreover, the proportion of ash to combustible matter is usually much larger in coke than it is in coal. For domestic purposes, the late J. R. Napier,† showed that coke can be used economically in stoves. The result of the working of one of his stoves having about 24 sq. feet of heating surface in a room of about 5,000 cubic feet capacity was that the burning of 1 lb. of gas coke per hour for ten hours per day kept the room as fresh as, and fully warmer than, about 30 lbs. of the same coke burned in an isolated American open fire-place. In comparison with many ordinary open fire-places using good coal, he estimated that 10 lbs. of gas coke at 13*s.* per ton would do more work than 40 lbs. of coal at 20*s.* to 26*s.* per ton. When the fire was well lighted in the morning and charged with about 10 lbs. of coke, it required no more attention, but kept up a moderate heat until it expired in about ten to twelve hours after, so that the amount of labour involved was very small. Such a stove, moreover, prevents almost entirely the escape of

* See Galloway, "Treatise on Fuel."

† "Economy of Fuel in Domestic Arrangements"—"Proc. Phil. Soc. Glasg.," Feb. 4. 1874.

carbonic acid into the room which it is used to heat. The principle of conducting the waste gases downwards before allowing them to escape—now pretty common in stoves—was applied in this stove, and caused it to be more economical than stoves in which the waste gases were carried directly upwards to the chimney. These results have not been to any appreciable extent surpassed in more recent attempts to use coke. Stoves constructed almost entirely of fire-brick—such as that invented by Mr. J. Dunnachie—have advantages in the use of solid fuel, such as coke, in consequence of the regularity with which they radiate the heat of combustion, and the absence of the unpleasant effects of diffusion of the waste gases through the material of which the stoves are constructed, which diffusion, it has been shown by Deville and Troost, takes place through heated iron, causing the unpleasant smell which arises when cast-iron stoves are used.

In industrial applications, Mr. T. Fletcher* has shown that steam boilers can be economically fired with coke, provided the width and shallowness of the fire-box and flue are arranged to suit the character of the fuel. Under such circumstances, the results he quotes show an increased evaporative efficiency over that of the same boiler when fired with coal.

It is when we consider the application of gaseous fuel to industrial operations on the one hand, and to domestic purposes on the other, that we are met by the great variation which exists in the available means of supplying that fuel.

The magnitude of the industrial operations now carried out by means of gas firing, and, indeed, of manufacturing operations generally where gas fuel is or can be used, renders it imperative that a cheaper source of supply should be found than that which is available in the ordinary gas mains for supplying illuminating gas from gas works. Consequently, crude gas, such as is obtained from producers of the Wilson or Siemens type, or from some improved form of generator, is likely to find an increasing application in this field. Descriptions of these appliances and of various types of furnaces will be found at other pages. The following memoirs may also be consulted:—*Siemens*, in Jour. Chem. Soc., Proceedings Inst. C.E., &c.; *Wilson*, in Jour. Soc. Chem. Indus., Cleveland Inst. of Engineers; *Crowe*, Jour. Soc. Chem. Indus.; *F. J. Rowan*, Proc. Inst. Engineers in Scotland, Proc. Mining Inst. of Scotland; *W. S. Sutherland*, in Jour. Iron and Steel Inst.; *Chas. Hunt*, in Jour. Soc. Chem. Indus.; *Foulis* and others, in Proc. N. B. Assocn. of Gas Managers; in the *Chemiker Zeitung*, 1880; Percy's Metallurgy, vol. Fuel; &c. &c. Papers dealing with the chemical and thermochemical elements of the production of gas will be found, by *Morrison*, *L. T. Wright*, *G. Davis*, and others, in Jour. Soc. Chem. Industry; in *Chemisches Centralblatt*, by R. Schöffel; by *E. Minary*, in *Publication Industrielle des Machines Outils et Appareils*; in Engineering, and elsewhere; and these papers leave little, if anything, to be added to this branch of the subject.

To obtain high temperatures with poor gas, or gas mixed with a considerable proportion of nitrogen derived from the air used in the primary combustion of the fuel, "regeneration" or the heating of the air supply, or of both air and gas supply, is necessary, but moderate temperatures may be obtained by combustion of gas with cold air. High temperatures can also be obtained by the application of the blow-pipe on a large scale with only partial pre-heating of the air supply used for the combustion of the gas.

The so-called "flameless combustion" of Mr. T. Fletcher requires gaseous fuel for its production, and is an economical method of using that fuel when once the required temperature has been attained; while the carrying out

* Lecture on "Smokeless Houses and Manufactories" at the Parkes Museum of Hygiene, March 188 .

of the "heating by radiation" of Mr. F. Siemens is principally a question of a sufficiently large combustion chamber in which the gas and air may fairly unite.

For domestic purposes, the argument about the cost of the gas supply does not possess much force. With the improved gas heating and cooking appliances which are well known, the working cost, where ordinary illuminating gas is used, compares favourably with any other method of using fuel. Yet it has been proposed by Siemens and others that there should be a supply of heating gas having a lower illuminating power than the ordinary illuminating gas, provided by a second service of mains. The cost of plant for producing and conveying this second supply is, however, a very strong argument against its adoption, and the saving to the consumer is problematical, on account of the lower heating power of the proposed gas supply.

Domestic appliances for the economical utilization of gas are widely known and used. It may be here stated generally that ventilating gas stoves are much more economical than any form of open gas fires, or than the combined coke and gas fire of Siemens.

In view, however, of the fact, stated previously, that coke is at present produced, and that this calls for some method of utilizing it to form an outlet for such material, there is one method of working which has been suggested for the consideration of gas manufacturers. This is, in brief, to turn the whole of the fixed carbon of the coal into gas in the present gas works, making use in this process of the heat possessed by the coke when, in the ordinary course of working as at present, it is drawn from the retorts. The plan proposed is to have a secondary chamber or chambers, preferably vertical, closed to the atmosphere, but communicating with the distilling retorts at the end farthest from their charging doors, and heated externally by gas firing. The coke formed in the distilling retorts should be pushed (either continuously by a worm feeding in fresh coal, or periodically by a plunger arrangement) into the secondary chambers, where it can be decomposed into carbonic oxide by the action of superheated steam injected into the mass, the hydrogen set free by the decomposition of the steam also mixing with the gases. Oil or tar might be introduced into this portion of the apparatus in order, by its volatilization, to enrich the gas in illuminating qualities, and the whole yield of gas should be withdrawn from the combined apparatus by the same exit pipes and delivered through the existing mains.

Proposals have been made by Hislop and others to utilize the coke for the production of gas by steam after the coke has been withdrawn from the retorts and charged into separate producers. This method is also followed in most of the plans for the utilization of the coke for producing gas for heating the retorts. The suggestion alluded to above is, however, that the coke should not be withdrawn into the atmosphere at all, but should merely be removed into a secondary portion of the one gas-making apparatus, in which it should be exposed to an atmosphere of steam alone, the temperature requisite for the decomposition $C + H_2O = CO + H$ being maintained by heating the secondary chamber from the outside by gas, as the retorts are now heated.

The only objection likely to be urged against this plan is the fact that the water gas so produced has no illuminating power. This, however, can be overcome by adding hydrocarbons to the gas so produced, or by the use of such burners as Clamond's or Lewis's or Welsbach's, or other burners making use of the effect, exhibited by Tyndall, of the introduction of an incandescent solid into a flame of low luminosity.

Where it is advisable to utilize radiant heat, this principle might with advantage be more largely introduced into gas stoves than is done at present.

It is beyond the scope of the present volume to enter into full details as to the various methods that have been introduced for the application of fuel to the several wants of the different branches of manufacture. In many of these, the heat generated, not only performs the office of raising the temperature and changing the physical condition of the substances operated on, but very frequently, as in smelting, roasting, and other processes, it produces chemical reactions which do not take place at low temperatures. Under each branch of chemical manufacture, we propose to give a particular account of the heating or other arrangements in which fuel is employed, so that at present we shall confine our attention, firstly, to those plans which have been most generally adopted, or which recommend themselves to our notice, for securing a uniform temperature in private dwellings or public buildings at all seasons, whilst they promote the equally important object of an efficient ventilation; and, secondly, to a few illustrations of the mode of application of fuel in the more important processes of the arts or manufacture in which it is essential.

In order to render a room or dwelling comfortable, the air contained in the entire space must be kept as far as possible at a uniform temperature, ranging from 56° (13°.3 C.) to 70° F. (21°.1 C.), considerably higher, therefore, than that of the atmosphere during winter in most civilized countries. When air is warmed, it expands and becomes lighter, and, being a bad conductor of heat, a constant movement of the air is produced in any confined space into which a hot body is introduced. The warmer portions ascend and give place to the colder as long as the inequality of temperature continues, so that the internal temperature of a room can never be retained above that of the colder exterior without a constant circulation of the enclosed air.

The velocity acquired by this current depends on the extent of the heating surface employed, and on the difference of temperature between it and the air of the room; it is not, however, in direct proportion, but in the ratio of the square root. If the air in the room, for example, is 60° F., and the surface of the stove at one time 176° F., and at another 212° F., the current in the latter case will be $\sqrt{\frac{176-60}{212-60}} = \frac{1}{1.14}$ more rapid. Again, as heat from any source is communicated by radiation, as well as by conduction, the more distant layers of air become warmed by contact with bodies heated in this manner, and ascend in consequence. Rooms might be easily and quickly heated at a small cost of fuel, if several unavoidable circumstances did not combine to withdraw the heated air and diminish its temperature. In the first place, the walls of the room, the windows, and doors constantly absorb heat, and evolve it again externally. The amount of heat lost in this way varies with the nature of the material, and also directly as the difference of temperature of the two surfaces and inversely as the thickness. According to Box (Practical Treatise on Heat), this may be expressed by

$$C' = C \times d \div E,$$

where C' = the loss by conduction in units per square foot per hour, C = the conducting power of the material, E = the thickness in inches, and d = the difference of temperature of the two surfaces. Secondly, the air in the interior being warmer and lighter, and consequently not in equilibrium with the external air, all crevices in windows and doors will allow cold air to stream in from below, while hot air passes out above. Lastly, in order to render the atmosphere healthy and fit for respiration, it is absolutely necessary that the air which has once passed through the lungs and the skin should be replaced by fresh air, which must generally be supplied cold from the outside. According to Munke's estimate, the loss of heat from these

causes, after deducting what is necessarily incurred for ventilation, amounts in twelve hours to 5 times, and according to another estimate, to 6 times, the quantity of heat that is required to raise the temperature of the air confined in a room of ordinary dimensions to 68° F. Every special case, however, will require a separate estimate. This loss is partly compensated by the vital heat of the persons present in the room, as also by the lamps, gas, or candles which are burnt; but it is certain that the greater part of the fuel required for retaining the air of a room at the proper temperature is consumed in making up for this constant loss of heat. Double windows and doors, and similar contrivances, which enclose a stagnating layer of air, materially lessen the loss of heat. During the time that a door is open, the warm air streams out from above, whilst the cold enters from below, as may be observed by holding a lighted taper in the two regions, the current being more rapid the greater the difference of temperature between the external and internal air. It is very advantageous, therefore, to allow the doors to open into warmed ante-rooms, so that warm instead of cold air may be admitted. The loss of heat occasioned from these circumstances may be approximatively ascertained by observing how much the temperature of a room sinks in a given time after the extinction of the fire.

When the air of a room is to be heated, the surface from which the heat is evolved is constructed so as to combine the necessary arrangements for the combustion of the fuel and the conduction of the heat. All the contrivances for communicating heat to apartments, however they may vary in outward form and dimensions, comprise a space for the combustion of the fuel; an area from which the heat is diffused; and lastly, some means of creating a draught, generally a chimney or flue, to draw the necessary air and carry away the products of combustion. The two primary conditions which are essential to every arrangement are—the maintenance of a temperature capable of consuming the material, and the supply of the amount of air (oxygen) necessary for combustion. If either of these be neglected, as they invariably are to a certain extent in practice, imperfect combustion will be the result, and consequently a defective evolution of heat.

Chimneys.—The air that is required for combustion is sometimes supplied, as in metallurgical processes, by machines for the purpose, but in most cases, as in ordinary stoves, kitchen-ranges, copper-fires, &c., the heat itself is made subservient to the production of a draught by means of a chimney. A *chimney* is a narrow channel, situated and extending to some height above the spot where combustion is going on, and the diameter of which, whatever may be its form, must correspond, within certain limits, with the size of the fire, and communicate freely, above and below, with the air. When cold, the column of air which occupies the interior of the chimney is in equilibrium with a column of equal magnitude without; a condition which ceases, however, as soon as the fire begins to warm the internal column, expanding it, and rendering it lighter. The equilibrium being then destroyed, the external air enters the space left vacant by the ascending inner column, is again heated in its turn, and gives place to another quantity of cold air, and so on; in short, a draught is created which lasts during the whole time of combustion. The difference of weight between the external and internal column of air is increased or diminished with the height of the chimney within certain limits, and by its temperature. We know that air is expanded $\frac{1}{459}$th of its volume for every additional 1° F. of temperature; in a channel of constant diameter, this may be measured directly by the height. If h represent the height of the chimney, and t the difference of temperature between the external and internal column of air, we shall have $h - \frac{ht}{459} = h\left(1 - \frac{t}{459}\right) = h'$, as the height of the internal column of air, supposing it to have the same

temperature as the external. The former is therefore shorter than the latter, by $h - h'$, or $h - h\left(1 - \frac{t}{459}\right) = \frac{ht}{459}$, a difference of height through which the latter must fall in order to enter the chimney. The velocity which it has acquired at the end of its descent, is just that with which the air in the chimney is moving, and, according to the law of falling bodies, just double that of the acceleration gained during the descent.* In the supposed instance, where $s = \frac{ht}{459}$, we have, therefore, $c = 2\sqrt{g\,\frac{ht}{459}}$ as the velocity, which must obtain, according to theory. This formula, however, is based on assumed conditions, which are never actually present in practice, and experience has shown that the real velocity in a chimney, on account of irregularity in the walls, and retarded flow of air through grate and fuel, as well as on account of the altered chemical nature of the latter, &c., remains so far behind the theoretically calculated velocity, that the latter cannot be employed to represent it with accuracy.

The retarding influences may partly be made the subject of calculation, so far at least as is necessary to understand the mode of their operation. The friction which the current of air suffers against the inner sides of the chimney is an obstacle of some importance; the force of the current is partially broken by coming in contact with the rough sides, and the velocity is lessened as the number of the irregularities increases; the height of the chimney, the force with which the reverberation occurs, or the velocity of the current, and lastly, the nature of the material composing the chimney, will all influence the ultimate result. Common brickwork, covered with mortar, offers much more resistance than cast- or sheet-iron. A narrow chimney, under the same circumstances, will offer more resistance than a wide one, as in the latter a greater portion of the column of air will pass through the centre of the chimney, and not touch the sides. In a very narrow channel, every particle of air may come in contact with the sides. The friction, therefore, is generally diminished by an increase in diameter. It has been found that the actual velocity of the current is considerably below what it should be according to calculation, even when the retarding influences, the amount of which has been determined by experiment, are taken into consideration. Various other causes may be adduced to account for this diminished velocity, such as the helical motion of the gases, as shown by Mr. James Mactear, the want of regularity in the supply, the accumulation of soot in the chimney, and stoppage of the grate by ash; these are unavoidably connected with the practical use of fuel.

Chimney Gases.—The introduction of the regulations imposed upon chemical manufacturers by the Alkali Acts, commencing in 1863, and especially those of 1874, caused attention to be directed to the gases escaping from chimneys in a measure previously unknown, and, as several methods for ascertaining the velocity of these escaping gases were tried, a good deal of information regarding their movements in chimneys was collected. Some careful experiments were carried out by Mr. James Mactear at St. Rollox, and, as he investigated the velocity of the gases at various distances from the centre of the chimney on several radial lines, his results are much more trustworthy than any taken on merely one diameter line could be.

The Annual Reports of the inspectors under these Alkali Acts contain

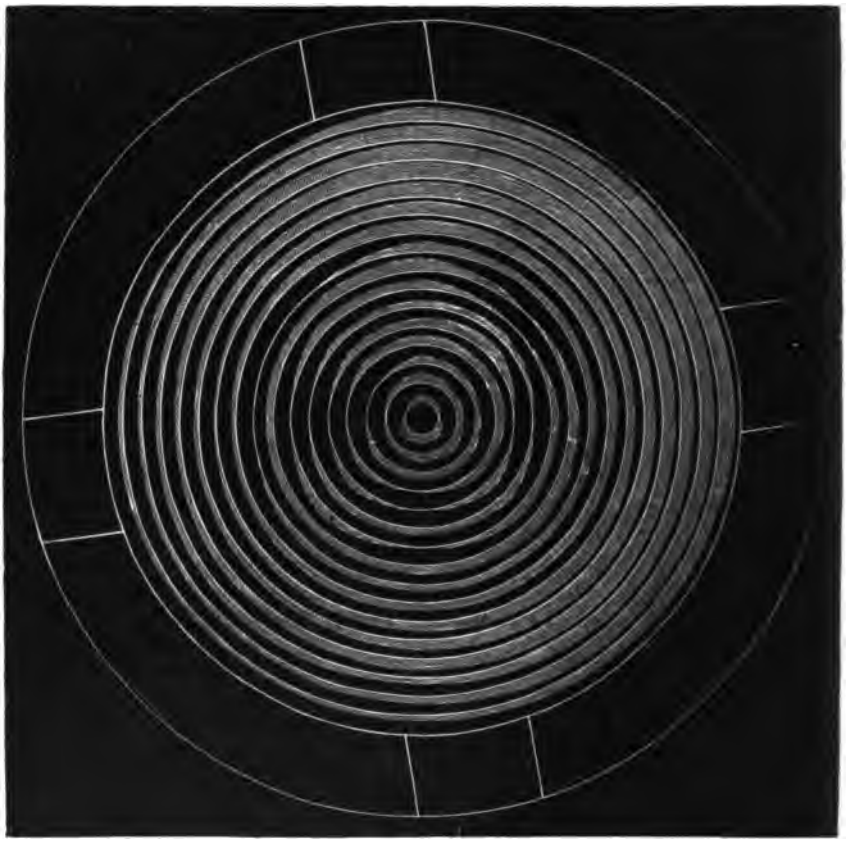
* If g represent the space which is traversed in a second (15 feet), t the duration of the descent in seconds, s the space passed through in the time t, and c the acquired velocity, we obtain $c = 2gt$. And because the space traversed is proportional to the square of the time occupied, or $s = gt^2$, it follows that

$$t = \sqrt{\frac{s}{g}}, \text{ and hence } c = 2g\sqrt{\frac{s}{g}} = 2\sqrt{gs}.$$

the results of many experiments by Mr. Fletcher, Dr. Dobson, Dr. Angus Smith, and others, which are of great value in connection with this subject.

For our present purpose, it suffices to say that Mr. Mactear found that the current of gases in flues and chimneys partakes of a spiral vortex motion, best illustrated by the motion of a loosely twisted strand of lamp cotton coiled in a glass tube, the end of which is twisted inwards by the hand; the fibres travel inwards towards the centre, and also in a spiral direction upwards towards the top. This is illustrated by his diagram of a section of the chimney (Fig. 223). As to the speed of these gases, whilst Mr. Fletcher found in some instances that the average speed was obtained at $\frac{1}{3}$rd of the

FIG. 223.

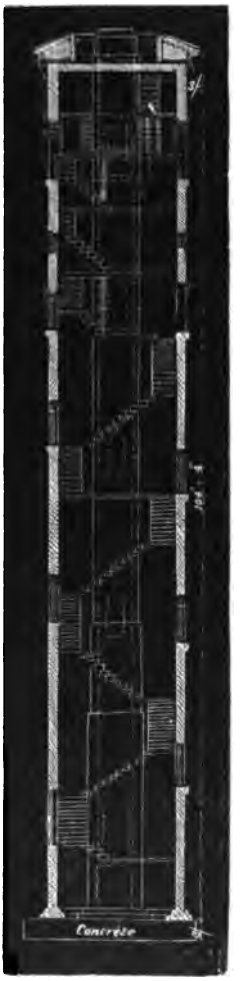


radius from the outside of a flue or chimney (as Péclet indicated in his *Traité de la Chaleur*), Mr. Mactear's results do not agree with this, but place the point of greatest speed nearer to the outside. In various tables of chimney speeds given in the Alkali Report for 1874, the maximum speed is found in his experiments at 2 feet from the wall of the chimney; in Dr. Hobson's, at 6 feet from the wall; and in Mr. Fletcher's, in one case 1 foot 6 inches from the wall, in the other case the same speed was obtained at 3 inches and at 12 inches from the wall.

It is interesting to know to what extent the friction in a chimney may be practically lessened by increasing its diameter and augmenting the internal temperature. It was stated above that the disadvantages attending

the heightening of a chimney may be counteracted by widening at the same time; but calculation proves that this must very soon find a limit, as does indeed occur when the height of the (round) chimney exceeds its diameter thirty or forty times. By an ingenious contrivance, these narrow limits have been extended. The contrivance is this: the entrance of the chimney remaining unchanged in dimensions, the upper part is suddenly considerably widened, the extended diameter being preserved throughout its entire length; thus the necessary quantity of air passes through the grate and fuel with undiminished velocity—and this is the real object of the draught—but, spreading itself out afterwards in the wider channel, it ascends more slowly and with proportionally diminished friction. It may be shown by calculation that the greatest advantage is obtained when the mouth is $\frac{1}{4}$th the width of the chimney. An increase of width obviously involves an extension of the mass of brickwork, and with it the amount of cooling must also increase. There will, therefore, be a certain ratio between these, when the advantage of diminished friction will be counterbalanced by the disadvantage of cooling. The principle on which chimneys are constructed supposes the draught to increase in proportion as the temperature of the internal exceeds that of the external column of air; this, however, occurs in a less proportion (in the ratio of the square root) than the increase of temperature; so that above 250° C. (482° F.) no increase of draught is obtained when the height of the chimney is twenty times its breadth. When one portion of the chimney is horizontal, no great difference in its action is observable, provided the entire height be not diminished; but the friction and cooling effects are somewhat increased. All contractions above the entrance or mouth must, however, be carefully avoided. Wind often materially interferes with the draught in chimneys, and its action is difficult to overcome; it may sometimes be counteracted by heightening the chimney and increasing the draught, or by adapting some arrangement to the summit to prevent the pressure it exerts from acting below a certain height.

Fig. 224.



Manufacturers are in the habit of building their chimneys of such diameter and capacity as will more than suffice for the work to be done, in order that an increase of work may not involve the expense of an additional chimney, the flues from new furnaces being carried into the general stack. When this precaution has not been observed, the old erection may be made capable of effecting more work by inclosing it with an outer wall, as in the following case.

The chimney constructed at Mr. Cubitt's works, at Millbank, having been found, as originally erected, insufficient for the work which it afterwards had to perform, and its strength being incapable of bearing any addition to its height, it was enclosed in the tower (Fig. 224), which was an ornament to that part of the metropolis. The draught became more than adequate for all the extra work which had to be performed, and the saving of the heat previously lost by radiation effected a considerable reduction in the quantity of fuel consumed.

The temperature of the interior, about one-third up, was 450°, and at the top 213° F. The expansion during the week was very considerable from the accumulation of heat, and the interior of the tower was maintained at summer temperature by the radiation of the heat from the sides of the chimney.

Chimney Draught.—Rankine ("Steam Engine," p. 286) gives some useful formulæ connected with the subject of chimney draught, in which the scale of *absolute temperatures* is made use of. Assuming that the volume of gas (or waste gases) from a furnace at 32° F. is 12½ cubic feet for each lb. of air supplied to the furnace, the volume of these gases at any other temperature T is

$$V = \text{volume at } 32^\circ \times \frac{T + 461^\circ.2}{493^\circ.2} = V_0 \cdot \frac{\tau}{\tau_0} \qquad (1)$$

A table of results of this calculation at different temperatures is given by Rankine.

If w denotes the weight of fuel burned in a given furnace *per second*;

V_0, the volume at 32° of the air supplied per lb. of fuel;

τ_1, the absolute temperature of the gas discharged by the chimney;

A, the sectional area of the chimney;

τ_0 being the absolute temperature of melting ice in degrees Fahrenheit; then the velocity of the current in the chimney in feet per second is

$$u = \frac{wV_0\tau_1}{A\tau_0} \qquad (2)$$

and the density of that current in lbs. to the cubic foot is very nearly

$$D = \frac{\tau_0}{\tau_1}\left(0.0807 + \frac{1}{V_0}\right) \qquad (3)$$

that is to say, from 0.084 to 0.087 $\times\ \tau_0 \div \tau_1$.

The "head" required to produce this draught is, according to a formula of Péclet, given by the equation

$$h = \frac{u^2}{2g}\left(1 + G + \frac{fl}{m}\right) \qquad (4)$$

where—

l denotes the whole length of the chimney and of the flue leading to it, in feet;

m denotes its "hydraulic mean depth," that is, its area divided by its perimeter, which for a square or round flue and chimney is one quarter of the diameter;

f is a co-efficient of friction, whose value for currents of gas moving over sooty surfaces is estimated by Péclet at 0.012; and

G is a factor of resistance for the passage of the air through the grate and the layer of fuel above it, whose value, according to the experiments of Péclet on furnaces burning from 20 to 24 lbs. of coal per square foot of grate, is 12.

Applying these values assigned by Péclet to the constants, then equation (4) becomes

$$h = \frac{u^2}{2g}\left(13 + \frac{0.012l}{m}\right) \qquad (4a)$$

It appears that, in using this formula, a conical or pyramidal chimney may, without sensible error, be treated as if it were cylindrical or prismatic, with a uniform sectional area equal to that of the opening at the top. The same formula enables the velocity u to be computed when the head h is given. The head h is expressed in feet in height of a column of the hot gas in the chimney. It may be converted into an equivalent pressure in pounds on the square foot by multiplying by the density as found by equation (3); thus:—

$$p = hD \qquad (5)$$

and to express the head in inches of water the multiplier 0.192 is used; thus:—

$$\text{Head in inches of water} = 0.192p = 0.192hD \qquad (6)$$

The head is in practice produced either by the ascensional force of the column of heated gases in the chimney, or by mechanical means such as a steam-jet or blast-pipe as used in locomotives, or a blower or fan forcing air through the fire or into the combustion chamber, or a steam-jet under-grate blower.

For a given external temperature, Rankine remarks that there is a certain temperature within the chimney which produces the most effective draught—that is, the maximum weight of hot gas discharged per second. This may be found by calculation, which shows that "the best chimney-draught takes place when the absolute temperature of the gas in the chimney is to that of the external air as 25 to 12," or when the density of the hot gas is one-half that of the external air.

Rankine adds that it may be laid down as a practical rule that, to insure the best possible draught through a given chimney, the temperature of the hot gas in the chimney should be nearly, but not quite, sufficient to melt lead.* As each pound of fuel consumed by means of an air-supply thus produced requires about 24 lbs. of air, the volume of hot gases discharged by the chimney is considerable, and the amount of heat carried off in this way constitutes one of the most serious sources of loss inseparable from this method of working.

For rapid combustion where the size of chimney is restricted, as in locomotives, a steam-blast is used. There is no economy of heat in this method of working, as the hot gases must escape at a high velocity, and they are drawn over the boiler surfaces to be heated too quickly to permit of their yielding up any large proportion of their heat to them.

The head produced by the blast-pipe is "equivalent to that portion of the atmospheric pressure which is balanced by the impact of the steam blast against the column of gas in the chimney," but its effect is of course dependent on the relative diameter and position of the blast-pipe to the dimensions of chimney, fire-box, &c.

The results given by Mr. D. K. Clark† show that in general the vacuum in the smoke-box of locomotives produced by the blast in the chimney is about 0.7 of the blast pressure, the vacuum in the fire-box is from one-third to one-half of that in the smoke-box, and that the rate of evaporation in the boiler varies nearly as the square root of the vacuum in the smoke-box. Mr. Clark also gives the best proportions of chimney, blast-pipe, smoke-box, and tube-surface to insure the best result with a given diameter of blast-pipe.

The employment of mechanical power for producing the head of pressure necessary for the air-supply of furnaces has not hitherto been much attended to, but it seems to offer great inducements for its introduction in the economy of heat which might be effected by this means. Péclet‡ directed attention to some of its advantages, and quoted a case in which a ventilator employed 6 h.p. in order to produce a given draught, which when obtained by chimney draught required a power equal to 50 h.p. C. Wye Williams§ made experiments on this subject, and proved that by mechanical draught the evaporative power of a boiler was increased from 1,552 to 2,454 lbs. of water evaporated per hour, and also the evaporative effect per pound of coal used was increased from 7.21 lbs. to 9.26 lbs.

Thos. Box,‖ considering the subject in connection with ventilation, has

* See Thos. Box, "A Practical Treatise on Heat," pp. 125–131.
† "Railway Machinery." ‡ *Traité de la Chaleur.*
§ "Fuel: its Combustion and Economy," pp. 134–138.
‖ "Practical Treatise on Heat," p. 281.

shown that, as regards the actual work done and heat consumed in doing it, the ratio of consumption of coal for mechanical ventilation to that required by a draught chimney is 1 to 11; and M. Minary,* by an exhaustive calculation, shows that to produce the movement of air in fires by the natural draught of chimneys we spend 26 times as much heat as we should need to spend in order to produce the same effect with a steam-engine driving a fan.

In both Mr. Box's and M. Minary's calculations a very low efficiency of fan was employed, and the usual efficiency for steam-engine was also taken, so that the result is not over-stated.

In a number of instances, it has become common to use an "under-grate blower" for the air-supply, instead of a fan. This blower consists of a jet of steam, arranged upon the "injector" principle, directed upon the contracted mouth of a tapered pipe, into which it carries an induced current of air along with it. The pipe discharges under the fire-bars into the ash-pit, which is closed, and a considerable pressure of air may be thus obtained, without the disadvantage to which the same air-supply delivered similarly by a fan would be open—viz., the melting of the fire-bars by an excessive local temperature. The decomposition of the steam of the blower in contact with the incandescent material at that point abstracts sufficient heat to preserve the bars. As to the economy or otherwise of under-grate blowers, this has not been investigated in the same way as the action of other blowers.

Forced Combustion.—The principles of what is now becoming well known under the name of "forced combustion" have been repeatedly advocated during past years by those who have devoted thought and study to the subject. The position assumed by them—which is now finding favour amongst engineers—has been, in brief, that the air-supply required for combustion in furnaces can be more economically furnished by mechanical power than by the action of chimneys; and the mechanical method has other advantages which entitles it to be preferred to the one that is older, but more imperfect. One of these advantages is the higher temperature of combustion which is produced, as this is equivalent, with a boiler of good design, to an increased evaporative power of boiler, or to increased evaporative effect from the fuel. Another advantage, which has not been fully realized in any plan as yet introduced into practical work, is that the rate of travel and escape of the flame and hot products of combustion is under control. It is thus possible to cool them more completely than can be done where chimney draught is used, and this means a saving of heat which would otherwise be uselessly dissipated.

Péclet† was one of the first, if not the first, to investigate this subject, and his conclusions were quoted with approval by the late C. Wye Williams in his treatise on the combustion of coal.

Péclet observed that, where the draught is created by the expenditure of fuel and heat, "the expense exceeds one-fourth of the combustible used. If we have not the means of otherwise employing that heat, the natural draught, by the chimney, is then admissible. If, however, that heat may be made available for the purposes of evaporation, and if a draught mechanically obtained would cost less, it would then be more advantageous to use it." In two cases which he cited, the balance in favour of mechanical production of draught was considerable, one of these being that of a brewery in which a ventilator worked by a 6 h.p. engine produced draught equal to the expenditure of 50 h.p. when draught was produced by means of a chimney.

* "The General Principles and Calculations connected with Combustion," in *Publication Industrielle*, &c., vol. xviii., livraison 5 6 (Paris).

† *Traité de la Chaleur.*

Péclet's results referred chiefly to the production of currents for ventilation, but Mr. Wye Williams applied his method to steam-raising with the following results :—

Experiments.	Coal used per Hour.	Water evaporated per Hour.	Water evaporated per lb. of Coal.	Pyrometer Heat in Flue.	Temperature of Escaping Gases.
1, with fan draught	265 lbs.	2,454 lbs.	9.26 lbs.	1,025° F.	650° F.
2, with ordinary chimney draught	215 „	1,552 „	7.21 „	725° „	410° „

Regarding these he remarks, "the effect produced by the fan draught was thus not only to increase the evaporative power of the boiler within the hour from 1,552 to 2,454 lbs. of water, but to increase the evaporative effect from each pound of coal used from 7.21 lbs. to 9.26 lbs."

The high temperature of the escaping gases in this case was due to the plan adopted by Mr. Williams, which was that of placing an exhausting fan in the flue beyond the boiler. This device, in common with that of the steam-blast in the funnel or chimney, as applied to locomotives, and that of a jet of steam or compressed air in the same position, must produce that result, as the effect in each case is to accelerate the rate of the travel of the hot gases over the heating surfaces and of their final escape, and thus to prevent them yielding up their heat even to the same degree as is possible with gases travelling more slowly under the action of chimney draught. The econony of heating effect is therefore entirely due to a higher temperature of combustion.

A very clear comparison between the two systems of producing draught was published by E. Minary* in 1868, of which the following gives the substance. The heat carried by the waste gases to the atmosphere, although lost for the industrial operation for which the fire is specially provided, is not, however, wholly lost, for it is utilized in producing the draught of the chimney by means of which a rapid current of air is established. This air, traversing the grate and the body of the fuel upon it, maintains combustion. In default of draught, we must have recourse to mechanical movement of air, either by fans or other blowing machines, or by the introduction of a jet of steam, as in locomotives, and in many tubular boilers which cannot have high enough chimneys.

The word "draught," which seems to indicate an aspiration or suction of the chimney, is not an exact expression. It has the inconvenience of suggesting a false idea of the movement of the air, and has thus prevented many practical men having a clear understanding of draught, besides helping to maintain a prejudice against the system of blowing fires by fans.

There is no aspiration, no suction, by the chimney. The current of air which incessantly traverses a fire is the result of the excess of pressure of air in front of the grate over that which exists immediately behind it. The diminution of pressure is due to the diminution of the density of the air which results from its expansion, with that of the gases of the fire, by the heat.

It is known that gases expand 0.367 of their volume for each 100 degrees C. If we suppose the air which fills a chimney suddenly elevated 200° C. in temperature, its volume will become $1 + (0.367 \times 2) = 1.734$. The internal capacity of the chimney being constant, all the increase of volume due to expansion escapes upwards.

The weight of a cubic metre of air which at zero was 1.293 kilo. becomes,

* *Publication Industrielle des Machines, &c.*, vol. xviii. (Paris).

at 200° C., equal to $\frac{1.293}{1.734} = 0.745$ kilo.; it has thus lost 0.548 kilo. per cubic metre.

Suppose a chimney of a square metre in sectional area and of 20 metres in height, the difference of pressure at the base of the chimney will be for 200° C. twenty times 0.548 kilo., or 10.960 kilos., corresponding to a column of water 0.01096 metre, or nearly 11 millimetres high. Under the influence of this pressure, the expanded air will have a velocity of escape equal to 16.94 metres per second, deducting for friction and for resistance offered by the chimney walls and by the changes of direction and of section.

Taking, for example, 1 kilo. of Blanzy coal having the composition, carbon 76.5, disposable hydrogen 3.1 per cent., the combustion of that quantity of the coal demands

Oxygen	2.288 kilos.	= 1.597 cubic metres
Nitrogen	7.660 „	= 6.098 „ „
Air	9.948 „	= 7.695 „ „

Calling this 7.700 cubic metres, the resulting gases (products of combustion) in escaping at 200° C. carry off the important quantity of 890 calories or nearly $\frac{1}{8}$th part of the heat produced by that quantity of fuel.

The diminution of pressure at the foot of a chimney of 20 metres height caused by the gases being raised 200° C. in temperature being equal to a column of water of 11 millimetres high, this is the pressure at which the air is supplied to the furnace.

Now, the mechanical work necessary to supply to a fire 7.700 cubic metres of air at this pressure, which corresponds to 10.100 kilos. on the surface of a square metre, will be 10.100 kilos. × 7.700 cubic metres = 77.7, or in round numbers 78 kilogrammetres.

The mechanical equivalent of 1 calorie being nearly 425 kilogrammetres, we thus find that the heat dispersed into the atmosphere by the gases at 200° C. causes the disappearance of power equivalent to 890 × 425 = 378,250 kilogrammetres in order to produce a useful effect equal to 78 kilogrammetres. The relation of the loss to the useful effect is thus, *theoretically*, $\frac{378,250}{78} = \frac{4,849}{1}$. To ascertain the *practical* relation of loss to useful effect we have to allow for the useful effect of steam engines and fans. Engines give out only 0.055 per cent. of the power of which the heat of steam is capable, and the useful effect of fans is not more than 0.10 to 0.20 per cent.

The practical relation at which we wish to arrive may therefore be expressed by $\frac{4,849 \times 0.0055}{1} = \frac{26.66}{1}$ which amounts to saying that to produce the movement of air in fires by the natural draught of chimneys we spend 26 times as much heat as we should need to spend in order to produce the same effect by means of a steam-engine driving a fan.

This result will be altered in favour of the mechanical method by the adoption of a higher temperature for the escaping gases. The quantities of heat carried off by these gases when discharged at 600° F. and 1000° F. respectively have been estimated by Mr. John Morrison,* who has also shown the advantage of transferring a portion of this waste heat to the supply of air used for combustion. Supposing 1 lb. of average Newcastle coal to be capable of yielding 10,000 heat units, and to require for its combustion an average of 24 lbs. of air, the waste gases would amount to 25 lbs., with the following result as to heat absorption :—

* On Combustion, "Jour. Soc. Chem. Ind.," vol. 1883, p. 79.

	lbs.	Spec. Heat.		
CO_2 . .	3.7	× .217	=	.8029
O . .	2.8	× .218	=	.6104
N . .	18.5	× .244	=	4.5140
	25.0			5.9273 heat units

necessary to raise the gases 1 degree F.

"Consequently, if these gases were discharged into the chimney at 600° F. over the initial atmospheric temperature, 5.9273 × 600 = 3,556 heat units out of a possible 10,000 would be entirely absorbed in draught production; while, if they were discharged at 1000° F. over the atmosphere, the loss with the same consumption of air would reach 5,927 heat units, an amount considerably exceeding one-half the entire calorific value of the fuel."

Regarding the transference of heat to the air-supply, which, with methods of forced combustion, is possible to an extent impracticable where chimney draught is employed to supply the necessary air, Mr. Morrison remarks:—"Supposing the provision of suitable arrangements for heating the air-supply free of expense (by means of the more or less highly heated waste gases) to a temperature of, say, 300° F. over the atmosphere, then 300 × .2374 (specific heat of air) = 71 units × 25 (air used for combustion) = 1,350* units, or 13½ per cent., would be added to the 10,000 produced with normal air; while, if the temperature were similarly increased by 600° and 1000° F., the augmentation of efficiency would respectively be 27 and 45 per cent. Or, in other words, with an air-supply exceeding the normal atmospheric temperature by 300°, 600°, and 1000° F., 17½, 14½, and 11 cwts. would respectively perform the duty of 1 ton of fuel burnt with a similar weight of ordinary cold air."

Methods of applying, in greater or less degree, the system of forced combustion to steam-boilers have been devised or described in this country after Prideaux by F. J. Rowan† (1876); Capt. Hamilton Geary, R.A.‡ (1877), as applied to burning anthracite in marine boilers; R. W. Perkins and J. F. Flannery§ (1880), also primarily for burning anthracite; R. J. Butler;‖ James Howden;¶ and R. Sennett, R.N.** Other plans†† may have been proposed, but those mentioned are sufficient to illustrate the subject. In all but the first two, the object aimed at has been merely to supply the air required for combustion at a rate sufficient to produce a higher temperature of combustion than is usually obtained with ordinary draught. Ventilation of the stokehold and the convenience of a closed stokehold caused the introduction of the system into vessels of the Royal Navy where economy of fuel was not an object in view.

In the first of the later plans mentioned, the purpose was to increase the pressure under which combustion was carried on in addition to supplying the air mechanically, the arrangement adopted for slightly increasing the pressure also providing means for retarding the escape of the gaseous products of combustion.

Mechanical or artificial draught thus presents to us a method of economically furnishing the air-supply to furnaces and producing a more efficient combustion temperature, while it also renders possible further economies due to retarding the movement and escape of the hot gases, to preliminary heating of the air-supply by waste heat or otherwise, and to carrying on combustion under a pressure higher than that of the atmosphere.

* This number should evidently have been 1,775; or, if 24 lbs. of air were assumed as above, then 1,700 units.—ED.

† British patent, No. 4,430—1876, "Min. Proc. Inst. C.E.," vol. liv. pp. 131, 172; "Engineering," vol. xxvi. pp. 164. 283; "Brit. Assoc. Reports," 1878.

‡ "Jour. Roy. U.S. Inst.," vol. xxi. p. 956. § "Trans. I.N.A.," vol. 1880.

‖ *Ibid.*, vol. 1883. ¶ *Ibid.*, vols. 1884 and 1886. ** *Ibid.*, vol. 1886.

†† See also "On Forced Draught," by J. Patterson and M. Sandison, "Trans. N.E. Coast Inst. Eng. and Shipbuilders," March 3, 1886.

The possibilities of combustion under increased pressure have scarcely been considered in a practical way as yet. Frankland's researches* and experiments serve to point out the way to what is a promising field of investigation, merely waiting for quantitative results to complete the qualitative work already done; but attempts at practical application have been few.

Bessemer introduced a very interesting system of high-pressure furnaces in the year 1869,† but evidently put it into practice only on a very limited scale. The following explanation of the principles involved in it, or in any similar plan, was, however, published by Mr. W. H. Maw :‡—"When combustion is carried on under pressure, the resulting products of combustion occupy a less space than they would if produced under the ordinary pressure of the atmosphere, and thus a portion of the heat which would have been rendered latent in causing their expansion is left available for raising their temperature. The experiments of Poisson and Laplace showed that the specific heat of air when maintained at a constant *volume* is but 0.169, whereas when maintained at a constant *pressure* it is 0.238 (that of water being unity), or, in other words, that a pound of air, in expanding to the extent corresponding to a rise of temperature of 1 degree, absorbs or renders latent 0.238 − 0.169 = 0.069 of a unit of heat. It is this fact which explains the heating of air which takes place when it is compressed, the heat which had been employed in maintaining it in an expanded state being by the act of compression rendered sensible, and the temperature of the air raised accordingly. The compression of the air does not increase the quantity of heat contained in it, but merely renders sensible a portion previously latent.

"Now, in carrying on combustion under pressure, the products are not allowed to expand and then be heated by re-compression, but they are prevented from expanding as they would under ordinary circumstances, and, so far as effects go, the results are the same. In other words, the temperature to be expected in a high-pressure furnace working at a pressure of, say, two atmospheres, will be the same as if the products obtained by combustion under ordinary atmospheric pressure were, before becoming at all cooled, suddenly compressed to one-half their volume. The increase of temperature due to compression in this way may be calculated by the well-known formula for air :—

$$T = \left\{ (t + 461.2) \times \left(\frac{P}{p}\right)^{0.29} \right\} - 461.2,$$

t and T being the temperatures (in degrees Fahrenheit) before and after compression respectively, and p and P being the corresponding total pressures above a vacuum.

"Assuming, as we probably may without sensible error, that this formula for air is applicable to the gaseous products of combustion of a high-pressure furnace, the theoretical increase of temperature due to the adoption of the high-pressure system in any particular case may be readily calculated.

"For example, let us suppose the case of a furnace in which the proportions of carbonic acid and carbonic oxide in the products of combustion are such that, when the combustion is carried on at the ordinary atmospheric pressure, these products are heated 2,700 degrees above the normal temperature of the air and fuel; and let us ascertain what may be expected to take place if the pressure under which the furnace is worked be increased to two atmospheres. Taking the normal temperature of the air and fuel at 60 degrees, the temperature of the products of combustion obtained at

* See "Experimental Researches;" also "Jour. Chem. Soc.," vol. xvii. 1864, pp. 52–55; "Brit. Assoc. Reports," vol. xxxviii. p. 37; "Proc. Roy. Soc.," vol. xvi. (1868); "Phil. Mag.," vol. xxxvi. (1868), pp. 309–311.

† See "Engineering," vol. 1869, pp. 197, 261.

‡ See "Proc. Cleveland Inst. of Engineers," Feb. 9, 1871.

ordinary atmospheric pressure under the above circumstances will be 2,760°, and, substituting this temperature for t in the formula, we get for temperature under a pressure of two atmospheres—

$$T = \left\{ (2{,}760 + 461.2) \times \left(\frac{2}{1}\right)^{0.29} \right\} - 461.2 =$$

$$(3{,}221.2 \times 1.222) - 461.2 = 3{,}475^{\circ}.1.$$

or say 3,475 degrees, a temperature 715° higher than that obtained when the combustion took place under ordinary atmospheric pressure. A similar calculation will show that, by increasing the pressure under which combustion is carried on to three atmospheres, a further increase of temperature to the extent of 493° may theoretically be expected."

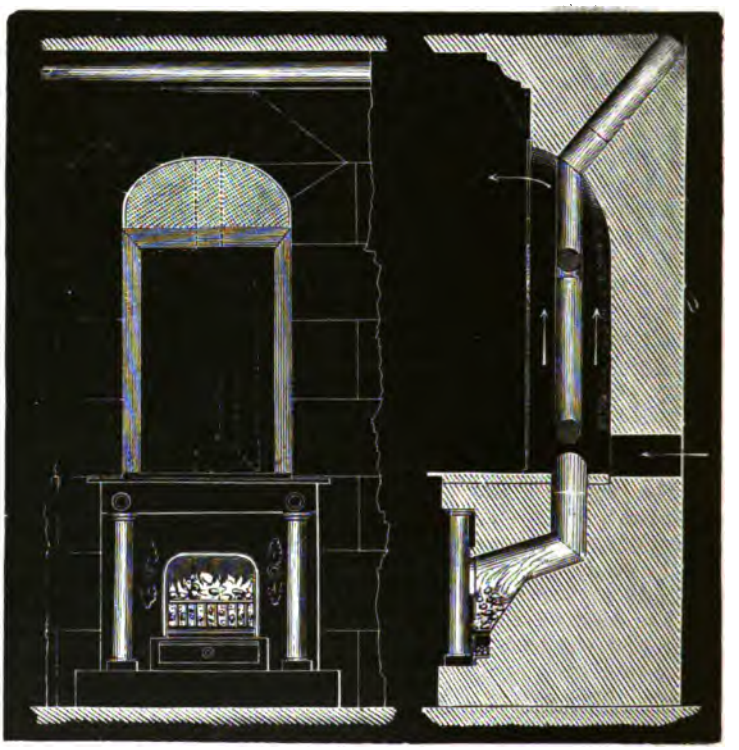
Fire-grate.—The most important part of the fire-place is the support for the fuel; it is generally constructed of iron bars, which admit air to the fuel, and is called the *grate*. The spaces between the bars of the grate should be wide enough to allow the ash to fall through, and at the same time sufficiently contracted to support the fuel. In many stoves and boiler fires, no other entrance to the chimney is afforded except through the bars, and their shape, as well as the distance between them, exerts considerable influence on the draught. The bars should be wedge-shaped, the wide side of the wedge being placed uppermost in the grate, and the total area for the admission of air between them should be, with reference to the diameter of the chimney, in the ratio of 1 : 4. As, however, a great part of the open grate surface is necessarily clogged with fuel while the process of combustion is going on, and some fuels offer much more impediment to the draught than others, no data generally applicable for the construction of grates, with reference to the relative areas of open grate surface and chimney vent, can be given, although, as a near approach to the ratio above stated, the practical rule is to leave an open grate surface equal in dimensions to the diameter of the flue. The greater the heating power of the fuel, the wider may be the grate, and *vice versâ*. No grate is absolutely requisite when wood is used, the necessary air being admitted by holes in the door, and when either liquid or gaseous fuel is used the grate is dispensed with, a combustion chamber lined with fire-brick being all that is necessary. The shape of the grate is of less importance; but when it aids the uniform sinking of the fuel, and is deepened or basket-shaped, it may materially assist the process of combustion. A very superior form of grate for large boiler fires will be described below, in connection with the prevention of smoke.

Methods of heating Apartments and Dwellings.—In order thoroughly to understand the principles of applying heat, it is necessary to remember that the heat evolved from fuel is disseminated to surrounding bodies by *radiation*, by *immediate contact*, and by *convection*, or the transmission of the heat of combustion by volumes of air or gases. Péclet has examined these points, with the aid of a very ingenious apparatus. He surrounded fuel, contained in a round wire basket, with a ring-shaped vessel, in such a manner that the quantity of water contained in the latter could be heated only by radiation from the surface of the globular basket. By comparing the size of the radiating surface with the quantity and the temperature of the heated water, it was found that the radiated heat from wood was $\frac{1}{4}$th, from wood charcoal $\frac{1}{2}$, from coal about as much, and from peat and peat charcoal $\frac{1}{12}$th of the whole amount of heat evolved. As a general result, the combustibles which burnt with the least flame yielded the most radiant heat. The radiant heat is therefore nearly always the smaller quantity, and, on that account, the arrangements in which it alone is employed are not economical for heating the air of dwellings.

Open Fire-place.—The open fire-place, or hearth, is the most ancient mode of heating dwellings, and, although it affords only radiant heat to the

room, is still very generally employed in France and England. The fire-basket, or grate, is placed immediately below the chimney, which is widened into a recess to receive it; the fire thus burns unenclosed in the room, whence it draws the necessary air for the combustion of the fuel; the air becomes heated and passes off with the smoke into the chimney without parting with any portion of its heat to the atmosphere of the room. It is almost impossible to regulate the quantity of air supplied to an open fire-place, and a considerable portion of the warmed air of the room is uselessly carried off by the draught, although no doubt a portion of this heat warms the floors above. Thus the only way in which the fire can warm the air is by radiation. All the improvements made by Rumford and others on open grates tend to facilitate radiation towards the room, to make use of the escaping air as much as possible without injuring the draught, and, lastly, to regulate the draught.

FIG. 225.



The grate is frequently brought forward from the wall of the chimney, and the sides of the recess are so constructed that their inner surface, acting like the reflector of a lamp, shall collect the rays of heat and reflect them into the room; the size of the recess is sometimes lessened and fitted with dampers to prevent loss of heat, which, however, must always be very considerable in every open fire-place.

Numerous contrivances have at different times been invented for economizing the heat of the smoke and gases, which, in the ordinary arrangement of the open fire-place, pass directly into the chimney without parting with any portion of their heat. One such is shown in Fig. 225, adapted to a coal fire. The products of combustion here ascend through an iron pipe, which may be lengthened by bends to increase the heating surface.

This pipe is placed in a cavity of the wall above the mantel, which is connected at the lower extremity with a channel which communicates with the external air. Fresh air is thus warmed by contact with the pipe conveying the smoke and heated gases, and delivered into the room through a grating in connection with the upper part of the cavity. The objections to all such arrangements consist in the difficulty of cleaning the pipes, and the danger of mixing smoke with the fresh air from imperfection in the joints.

A stove fire-place, which combines the advantages of the open grate with those of the close stove, was invented by Desarnod. It is constructed of plate-iron, and stands forward and isolated in the room, an iron plate being fixed at the back, through a slit in which the smoke passes to a series of pipes, which it traverses before being carried to the chimney. The room is then warmed, not only by radiation, but also by the immediate contact of the air of the room with the heated iron plate and the pipe in which the smoke circulates. Desarnod's stove fire-place is very similar in principle to that described below.

The numerous advantages of an open fire-place are so highly valued by the inhabitants of this country, whose ideas of comfort and sociability are intimately connected with the fire-side, that it is not likely that other modes of heating rooms or dwellings will ever entirely supersede this old-established plan of obtaining the necessary amount of warmth. The open fire-place and chimney afford a very simple means of creating a circulation of air throughout the inhabited room, with which it is impossible to dispense without injury to health, and which is entirely absent in those arrangements on the Continent, where the fuel is introduced into the stove and supplied with the requisite amount of air from without. The ventilation of the rooms is then entirely dependent on crevices in windows and doors, and as these are avoided as much as possible in the construction of the houses, double windows and double doors being frequently employed, the air becomes vitiated in a very short time, especially where many persons are present, and the sallow complexions or stove-dried appearance of the occupants of such dwelling-rooms is one of the visible signs of their injurious tendency.

The ordinary arrangement of the fire-places in our dwelling-houses at present, however, is very defective. There is always a considerable loss of heat, the very unequal temperature diffused through the different parts of a room being exclusively derived from the radiant heat of an open fire. The only supply of air to the fuel is furnished by the crevices in doors, windows, or floors; and persons sitting by the fire invariably experience the unpleasant sensation of excessive heat on the side exposed to it, while the other is cooled to an equally disagreeable extent by cold air rushing in from these different sources to maintain the combustion of the fuel. The ventilation produced by the open fire-place is very partial, as currents are produced only in the lower strata of the atmosphere of a room, while the upper layers, in which the vitiated air collects when warm, are untouched by the chimney draught. Another objection to open fire-places and chimneys is the downward draught frequently occasioned in neighbouring chimneys not in use, by large powerful fires in other rooms of the same building, which are not supplied from other sources with sufficient air for the consumption of the fuel. Foul air, carrying with it particles of soot, is thus disseminated through the rooms, to the detriment of health and cleanliness.

The late Mr. Sylvester made several improvements on the open fire-hearth, which have been adopted with great advantage in many public offices as well as in private houses. In Sylvester's stoves, the fuel is placed upon a grate, the bars of which are on a level with the floor of the room, and air is supplied to the ash-pit below by a series of passages which pass under a hearth composed either of separate bars of iron, arranged in a radiating

manner in front of the grate, or of ornamental fire-tiles. The radiant and conducted heat from the fire is thus made to warm the hearth and the air passing below it, while the low position of the fire, and the inclination which may be given to the back and sides of the grate, tend to disseminate the heat much more effectually through the room than is usual in the ordinary arrangement of the fire-place. The sides and top of these stoves are constructed of double casings of iron, and in the sides a series of vertical plates is enclosed, parallel with the front facing, which collect, by conduction, a great portion of the heat generated from the fire, the mass of metal of which these are composed being so proportioned to the fuel consumed, that the air can never rise above the temperature of 212° F. under any circumstances. The sides and top of the stove are thus converted into a hot chamber, offering an extensive surface of heated metal; at the bottom, by an opening in the ornamental part, the air is allowed to enter, and rises as it becomes warmed, traversing in its ascent the different compartments formed by the hot parallel plates, and is allowed to escape at the top by some similar opening into the room. A current of air is thus constantly traversing the hollow sides and top of the stove, collecting the heat communicated to the metallic mass and disseminating it through the room. If allowed to enter the room

Fig. 226.

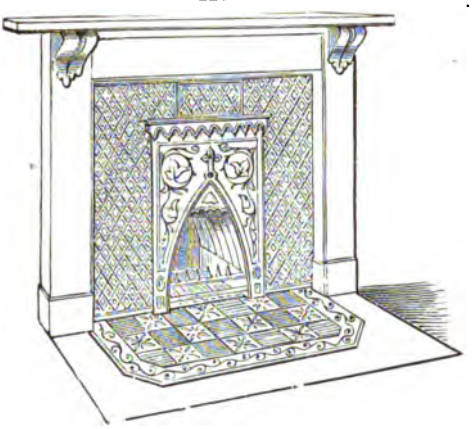
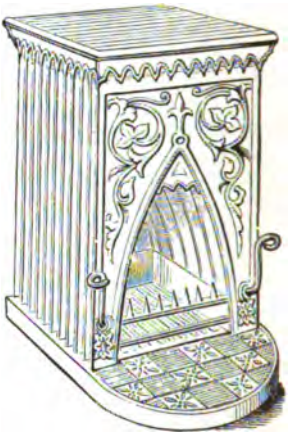


Fig. 227.

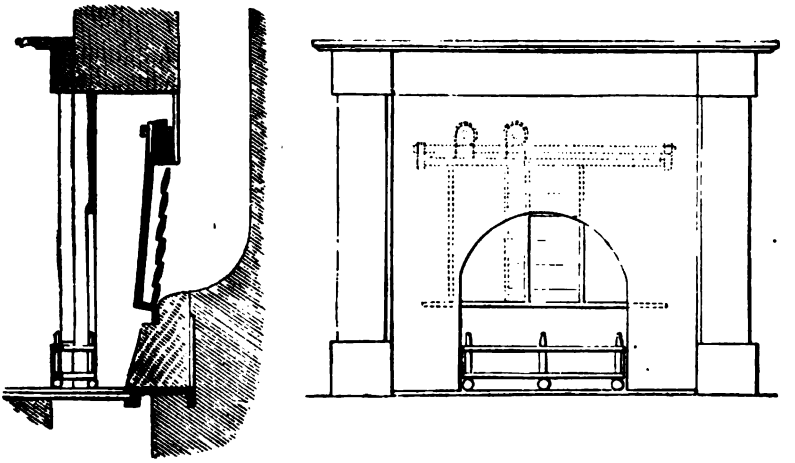


by the top aperture, the air would now be in the rarified, dry state, which is considered unwholesome; a basin of water is consequently introduced into the top of the stove, where it evaporates, communicating the proper amount of moisture to the air. Figs. 226 and 227 represent two of these stoves; the one, Fig. 227, is intended to stand forward in the room; the other, Fig. 226, to fit into the recess of an ordinary chimney. At the back of the grate is a series of louvres, by opening or closing which, a greater or less draught can be created, according to the amount of combustion required. The whole opening into the flue behind can be closed, when the fire is not in use, by sliding doors, shown in Fig. 228, which form a valuable addition to every chimney, and deserve more particular notice from their important applications to other technical purposes connected with the economical use of fuel. These doors are constructed in such a manner that they slide perfectly true upon the surface of metal behind them, a portion of their weight being distributed against the sliding surface, for the purpose of preserving contact; they are provided also with friction rollers to support them on their bearing bar, in order that they may be easily moved. Chimneys not in use can be completely closed by this contrivance, and the disagreeable downward currents,

mentioned above, are most effectually stopped by closing this door. These doors will also be found of much service in the case of a chimney taking fire, for by closing the door the access of air to the burning soot is prevented, and the fire speedily extinguished.

Applied to furnace or boiler fires and ash-pits, in the manner represented at Fig. 229, they afford a means of regulating the draught with great nicety,

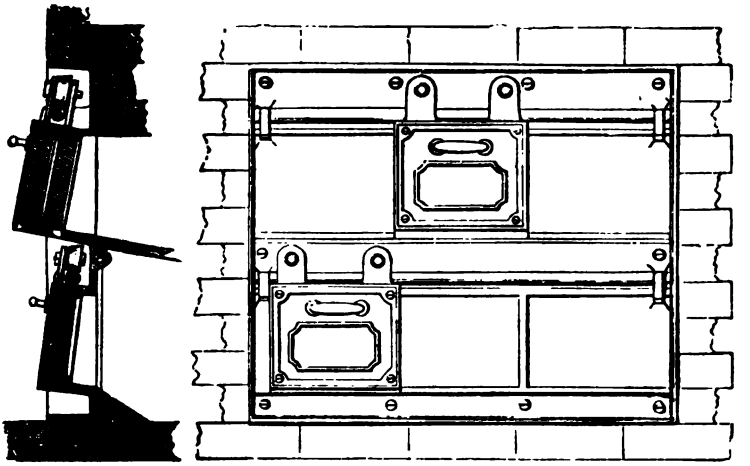
Fig. 228.



and thus supply one of the most important conditions for moderating the combustion of fuel. For these purposes they may be lined with fire-brick or clay.

The same contrivance, Fig. 230, is applied to the soot or flue doors introduced into chimneys for the purposes of cleansing, which can thus be accurately closed and side currents prevented.

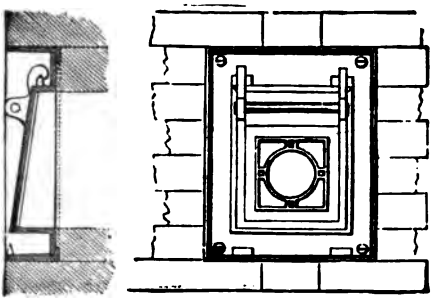
Fig. 229.



The economy of heat and fuel is very great in the stoves or fire-grates just described, but the air which supports combustion is supplied in the ordinary manner from adventitious sources, and the only mode of remedying this, with proper attention to ventilation at the same time, is by affording

a distinct entrance to pure air from without the building by some passage made expressly for that purpose. Mr. Sylvester recommends that a subterranean passage be made from the basement of every house to the garden, that the entrance to this passage be furnished with a revolving hood, which turns easily and presents an opening to the wind. The air which enters this passage is caused to traverse the heated sides of a large stove, constructed on the principle described above, and then passes on to the passages

Fig. 230.



and rooms of the whole house. The entrance of air by chance apertures and crevices is thus rendered unnecessary, and, if the supply from the air-channel be sufficient, there will be a tendency in the air to escape rather than enter. Cold currents of air will thus be replaced when required by warm currents, the circulation being kept up by small fires in each inhabited room, whilst the smaller consumption of fuel in each apartment will compensate for that consumed in the stove for heating the general supply of air.

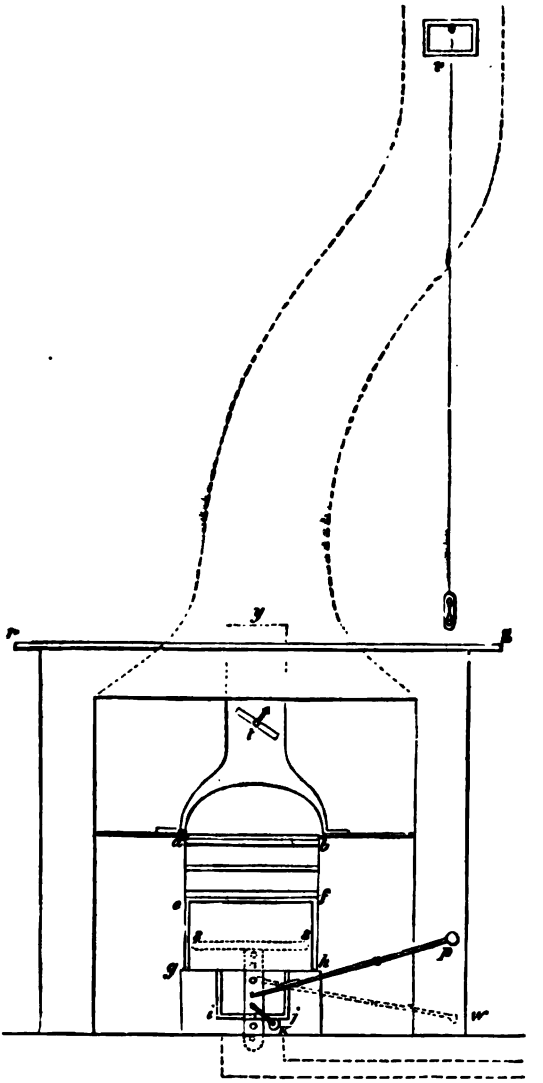
Improved Fire-places.—Several plans have been proposed for the improvement of open fire-places with the object of securing more perfect combustion and absence of smoke and soot, as well as of utilizing more of the heat of combustion by causing its transference to a body of fresh air continuously drawn from the outside of the chamber and passed in when warmed. General Morin suggested such improvements in France, and in Britain the late Dr. Neil Arnott, London, and Captain Douglas Galton have advocated and introduced excellent designs.

The improved fire-grate invented by Dr. Arnott succeeded in combining three very essential conditions, namely, the prevention of smoke and waste, the efficient warming and ventilation of rooms, and economy.

Arnott's Smoke-consuming and Fuel-saving Fire-place.—Smoke being caused by the imperfect combustion and cooling of gases containing large quantities of carbon, and which are always evolved when coal is heated to a temperature above 600° F., there is no possibility of preventing its production in a common grate, where fresh coal is being constantly added to the surface of the red-hot coke left from a former charge. The bituminous gases are evolved at the surface, where the fresh coal is heated, and in escaping through it to the chimney are so far cooled that a portion of carbon is invariably separated. Attempts have been made at different times, by Cutler and others, to ignite the coal at the surface of the charge in the grate and supply it from below; the gases produced from the fresh coal then pass through the red-hot coke in escaping to the chimney, and with a properly regulated supply of air must be entirely consumed. This plan, which is obviously correct in principle, has always failed in practice, on account of the complicated nature of the machinery required for raising the supply of coal to the place where it is consumed. Dr. Arnott appears in his plan, however, to have successfully overcome this obstacle. A drawing

of the grate is shown in Fig. 231, and represents a common fire-place with mantel *r s* or chimney-piece, two jambs, and common grate with two bars and bottom, to which four parts, the essentials of the new fire-place, are added. *e f g h* is a box, or receptacle of iron, to contain the charge of coal for the day, with its open mouth placed where the bottom bars of the grate had been. It may either stand on feet on the hearth, or be attached to the

Fig. 231.



grate; besides its fixed bottom, *g h*, it is also furnished with a movable one, *s s*, like a piston, on which the coal immediately rests, and is raised or lowered with the piston. A piston-rod passes through the fixed bottom, steadied by a guide-hole in the stirrup or bar, *i j*, below. The piston-rod has notches or openings in it to receive the points of the poker, *p o*, which, acting as a lever having its fulcrum in the foot of the box or otherwise, lifts

the piston. A catch, or pawl, *k*, falls into the notches as the piston rises, to prevent its return. No air whatever has access to the bottom of the fuel, the whole supply being derived through the front bars.

In the centre of the bottom front is a door, which may be opened to admit air if wanted, or for removing small coal or ashes which fall past the piston. Where the grate is set low, a small opening is made in the hearth to allow the end of the piston to descend.

A hood or cover, *a b y*, like an inverted funnel opened in front, is placed over the fire to contract the open space, receive the products of combustion, and convey them, little diluted with air, into the chimney-flue at *y*. This hood may be constructed of brick or of metal, and in the latter case may be converted into a boiler. A valve or damper, *t*, is placed in the narrow part of the stalk or the hood to give complete control of the current of air passing through. There is an external index, *t*, showing clearly the position of the valve within.

The direction of the chimney-flue in the wall is shown by *y v*, and is generally slanting, to avoid the fire-place of the room immediately above. A ventilating chimney-valve, *v*, admits air from near the top of the rooms to the flue; this is balanced nearly on its centre of gravity, so that the least pressure from without opens it inwards, but any pressure from within, as of smoke, closes it. There is a wire descending from the valve with a screw or loop-peg for partially or wholly closing it.

Underneath the hearth, a flue may be constructed by which fresh air, directly from the atmosphere, can enter the room to be warmed under the fender or near the fire, and then spread in the room: this also has a controlling-valve.

The saving of fuel by this arrangement is very great, one charge of the fire-box, or from 20 to 30 lbs. of coal, sufficing for the entire day, or, indeed, for a much longer period if, by regulating the supply of air, a very slow combustion is kept up. By means of the ventilator above, and the admission of air by the special channel from without to the part below the hearth, where it can become warmed before entering the room, the most perfect ventilation and a very equable temperature can be maintained.

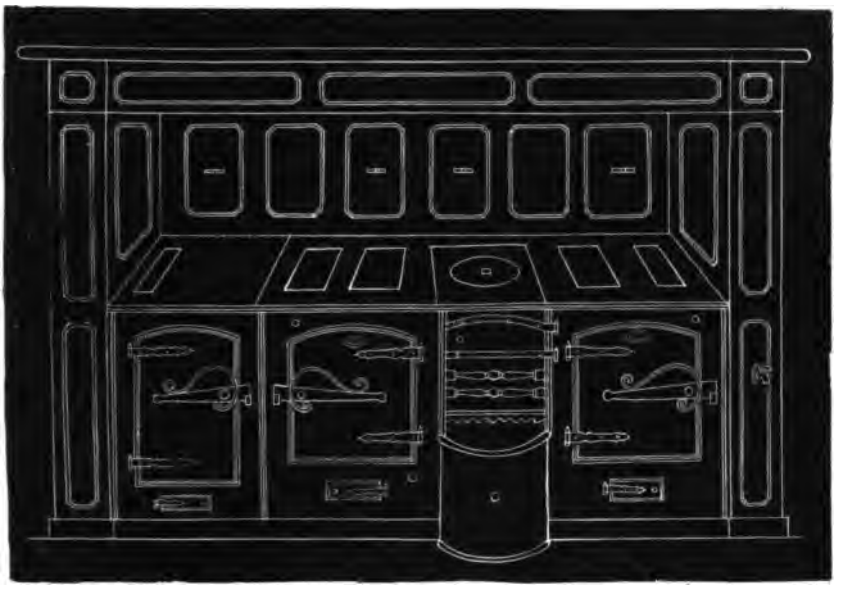
Some stoves or furnaces adapted for heating large volumes of air will be described below, in connection with the methods employed for warming and ventilating public buildings and spaces of large area, for which the radiant heat from open fire-places is totally insufficient.

The open fire-place is not well adapted for cooking purposes, and other arrangements are consequently much in use in the kitchens of this country. On the Continent, where wood or charcoal is the only fuel, and is both scarce and expensive, the economical application of it is even better understood. Count Rumford wrote elaborate essays on the construction of kitchen and other fire-places, ovens, roasters, &c., which, however, for many years produced but little effect on the general practice of the country, builders and house-fitters clinging most tenaciously to an immoderate use of iron in the construction of grates of all kinds. He strongly recommended a separate small fire for each oven, boiler, or roaster, and avoided the use of iron in the construction of the fire-places as much as possible.

Fig. 232 shows the arrangement of a kitchen range or "kitchener" which obtained a prize at the Great Exhibition of 1851. The fire-place is covered by an iron plate, in the centre of which, immediately above the fire, is a circular aperture closed by a disc of metal, when not occupied by the cooking utensils. The fire is only exposed at the bottom and front, and the upper part of the front, usually occupied by bars, can be shut by a short door, which converts the fire-place into a kind of furnace, the smoke being allowed to escape either through a flue immediately behind the fire into a

common chimney, or through one of the other flues terminating in the same and indicated by the positions of the several dampers at the back in the drawing. By means of this series of flues and dampers, the flame and hot gases can be carried round one or more of the ovens which are situated on either side of the fire, whilst a boiler at the back and on one side, with a supply-pipe to keep it always filled with water from a cistern, furnishes a constant supply of hot water.

Fig. 232.



This illustrates well the general construction of all the so-called "close ranges" or "kitcheners," but of late there has been a preference for arrangements by which the fire can at will be transformed into an open fire, so that roasting operations may be carried out. This is accomplished by exposing the front and top of the fire, and opening a communication with the chimney directly above the fire.

The Galton Grate.—The Galton grate* is arranged with the front projecting so as to radiate heat freely into the room; the smoke and waste gases are led into the chimney by a bent-nozzle pipe screwed on to the back of the fire-place, and the opening at the bottom of the grate is contracted by fire-brick, leaving only about one-third of the fire-space open in the centre, this open space being occupied by a small cast-iron grating through which alone air from below is supplied to the fire. The object in these arrangements is, as expressed by Capt. Galton, that, "whilst the draught is checked and the consumption of fuel reduced, a sufficient supply of air is obtained at the bottom to secure a cheerful fire and complete combustion." A clear space of half an inch is left behind the back fire-brick lump, through which space a supply of air passes up from the ash-pit, entering the fire-place through a hole or slit in the fire-brick back. The air thus heated comes in contact with the gases given off from the coal—the shape of the fire-brick back assisting this contact—and a pretty complete combustion is secured.

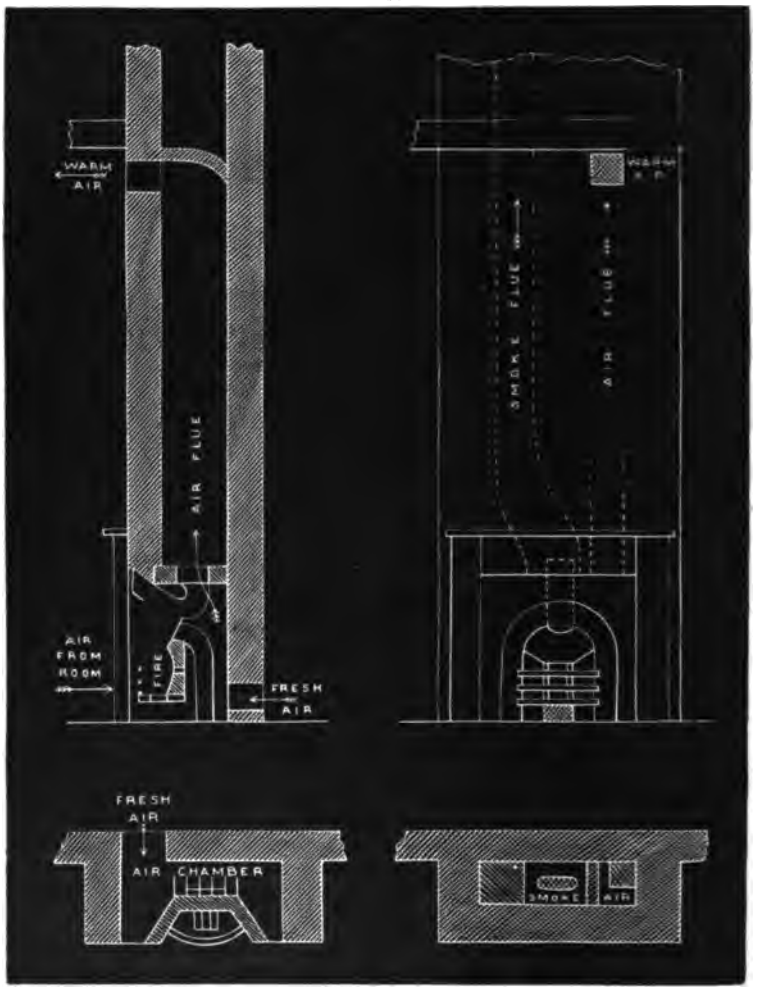
The iron of the grate and nozzle is so disposed that a good deal of the heat of the gases is imparted to it before they escape, the opposite surfaces

* See "Proc. Cleveland Inst. Engin.," March 15, 1875; "On Fuel," by C. W. Siemens, D.C.L.

of this iron being in contact with the fresh-air supply entering behind the grate. This air is heated by the radiation from the iron surfaces, and allowed to ascend by a separate shaft or by an iron pipe placed in the chimney, entering the room near the ceiling.

Fig. 233 shows both arrangements, and also the same general idea as applied to a stove. The same idea has been adapted for use with a gas-

FIG. 233.



burner for the ventilation and warming of rooms by Mr. Lawson Tait, M.R.C.S., of Birmingham, who has introduced his arrangement under the name of the Thermic Ventilator.

Experiments with the Galton grate carried out in Paris by Gen. Morin showed that, whilst with an ordinary fire-place the heat which is utilized in a room is only one-eighth (or 0.125) of the heat given off by the coal, in the Galton grate the heat utilized in the room was 0.355 of the heat given off by the coal, showing a saving of 0.233, or very nearly $\frac{1}{4}$th of the total heat which the coals can produce. The late Mr. Jas. R. Napier, F.R.S.,* however,

* On the Economy of Fuel in Domestic Arrangements, "Phil. Soc. Glasgow," Feb. 4, 1874.

maintained that, whilst the Galton fire lost over 60 per cent. of the total heat of combustion of the coal, the loss in close fires or stoves is only 5 to 10 per cent., and he consequently advocated their use for heating rooms. His own arrangement will be alluded to later.

The Siemens Coke Gas Fire.—The late Sir Wm. Siemens proposed an arrangement of open grate to use a combination of coke and gas in order to minimize labour in carrying fuel and ashes. A pipe led a supply of gas to a row of jets placed at the front of the grate along the bottom, whilst underneath the grate was a passage or chamber for air, formed either of iron (Fig. 234), or preferably of corrugated copper (Fig. 235), by means of

FIG. 234.

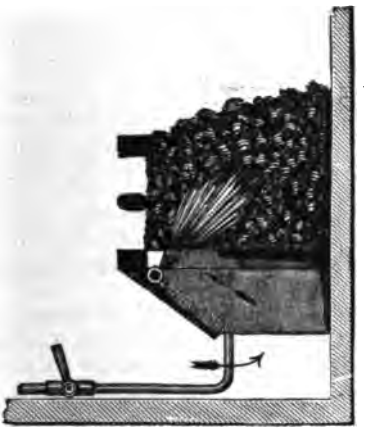
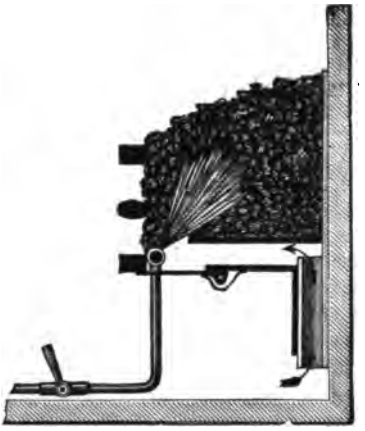


FIG. 235.



which the air-supply was heated by the radiation from the bottom of the grate. It was said that in the copper arrangement the heat was sufficient to melt lead, but whether the air passing in was heated to that temperature may be questioned, as the length of surface for it to travel over, and hence its time of contact with the hot surfaces, was short.

This grate was proposed with a view, not to economy, but to cleanliness and comfort, as a means of insuring a bright fire in a short space of time without entailing much trouble from supplying fuel or removing ashes.

Application of Gas as a Source of Heat.—Gas has long been employed as a source of heat in chemical and pharmaceutical laboratories, but it is only during the last few years that it has been more extensively used for cooking, and warming apartments. Under certain circumstances, gas may be a more economical fuel than coal; where heat is required quickly, and only for a short time, the waste which necessarily accompanies the lighting of a coal fire is far more than equivalent to the higher cost of the gas, which in large towns can be obtained at any moment, and, with proper contrivances, in the precise quantity required. It is estimated that for the four or five months in the year when a fire is not required for heating the kitchen, it is more economical to cook by gas in London than by a coal fire. With reference to the amount of water converted into steam by gas in ordinary burners, Mr. Evans obtained the following experimental results:—

One cubic foot of gas, weighing about 205 grains, and of specific gravity 0.413, boiled off $\frac{4}{10}$ths of a lb. of water, or 13.6 times its weight.

One cubic foot of gas, weighing about 290 grains, and of specific gravity 0.564, boiled off $\frac{6}{10}$ths of a lb. of water, or 12 times its weight.

One cubic foot of gas, weighing about 360 grains, and of specific gravity 0.700, boiled off $\frac{7}{10}$ths of a lb. of water, or 13.6 times its weight.

Theoretically, Newcastle coal gas, of specific gravity 0.416, has an evaporative value equal to about 22 times its weight; or, in other words, 1 lb. of such gas should convert 22 lbs. of water into steam: there is hence a loss of one-third at least of the heat evolved when the gas is consumed in the ordinary manner. Mr. Defries economized the heat to a great extent in his application of gas to the heating of baths; with 30 cubic feet of gas he heated 45 gallons, or 450 lbs. of water, from 50° F. to 100° F., and at a cost of only three-halfpence. This is equal to 15 lbs. similarly heated for each cubic foot of gas, weighing, say, 206 grains, or 750 lbs. of water heated 1 degree by the same means. Estimating the latent heat of steam at 960, this gives 25 parts of water boiled off for every 1 part of gas consumed, which is very nearly three times as great as the heating power of Newcastle coal.

Mr. Lewis Thompson finds that a gallon of water may be more economically brought to the boiling point by a gas stove than by a recently lighted coal fire; the relative cost of the two methods being as under:—

	Coal used.	Wood used.	Time employed.	Total Cost.
With fire . . .	4½ lbs.	⅛ of 1*d.*	1 hour	$\frac{11}{100}$ of 1*d.*
With gas . . .	4 cubic feet of gas at 4*s.* 6*d.* per 1,000.		20 minutes	$\frac{2\,2}{100}$ of 1*d.*

There is therefore, according to this estimate, an economy in cost of nearly 30 per cent., and a saving in time of two-thirds, besides great cleanliness and comfort in the use of gas.

The sight of a fire being considered indispensable to an Englishman's idea of comfort, inventors have endeavoured to imitate the combustion of solid fuel by causing a number of small gas jets to heat solid bodies to a high temperature, and thus produce the semblance of an ordinary coal fire. Among the ingenious contrivances for this purpose, Fig. 236 shows a

Fig. 236.

grate with the appearance presented when the jets of gas are ignited, and shavings of asbestos strewn over them: these become incandescent by the heat, and present the appearance of fuel.

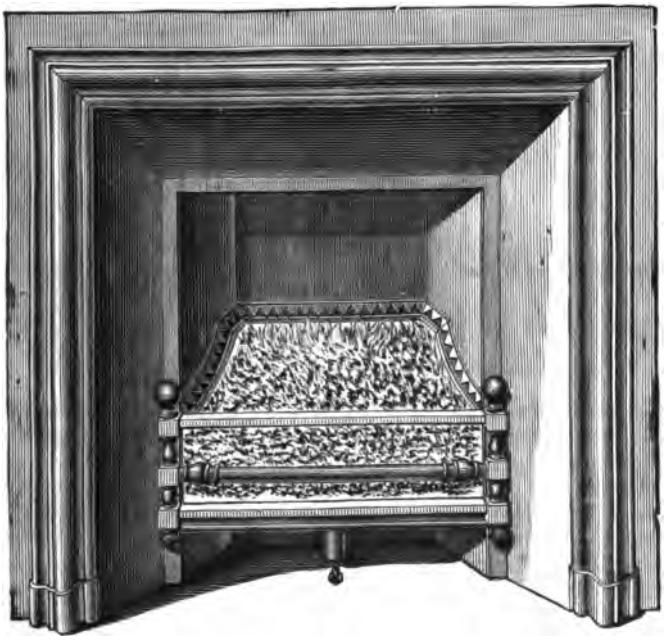
A fire of this kind for an ordinary room is estimated to consume about 7 feet of gas per hour, costing about 4*d.* for twelve hours. The asbestos, being incombustible, lasts for a great length of time, and sufficient can be obtained for 6*d.* for covering the bars. Various sized pieces of common peroxide of manganese, pumice-stone, and fire-brick have been substituted by some for the asbestos, and metallic platinum has been patented for this purpose by Bachhoffner and Defries, to produce what has been termed the polytechnic fire. This, though costly at first, is indestructible, and, as far as appear-

ance and comfort are concerned, is said to be most successful. By placing these gas grates under a chimney flue, perfect ventilation is secured. Although these inventions are limited at present to large towns where gas is comparatively cheap, and the pressure at the gas-holder is maintained during the day-time, yet it appears probable that their use for heating will extend as gas becomes more universally employed, and consequently cheaper. The extra cost of gas is often counterbalanced by the saving of labour, the absence of smoke, soot, and ashes, with the expenses attending their removal.

It must not be forgotten, however, that illuminating gas is a fuel costing, according to various estimates, from 6 to 10 times the price of coal, and that even allowing that its use saves labour, prevents dirt, lessens wear and tear, and abolishes smoke, yet it is necessary to use so expensive a fuel economically. In gas fires, unfortunately, we have a method of burning gas which presents conditions allowing of even a less duty being obtained from it than is obtained from coal. The amount of radiant heat from a gas fire is not equal to that of a good coal fire at its best, and the heat of convection in both cases is lost by chimney draught.

In the Report of the Proceedings of the North British Association of Gas Managers for 1881, Mr. G. R. Hislop (of Paisley) says that with his brother's gas fire about 20 cubic feet of gas per hour would be sufficient to warm a room of 18 feet × 14 feet (the height of the ceiling is not given), and smaller quantities for rooms of less dimensions. That amounts to about $\frac{3}{4}d.$ per

FIG. 237.



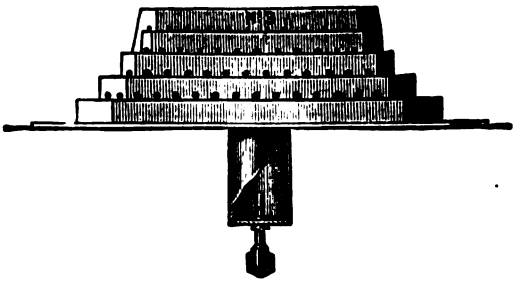
hour, taking gas at 4*s.* per 1,000 cubic feet. Other estimates made by users of gas fires, among which is that of Mr. W. Denny,* make the cost of them 1*d.* per hour, or slightly more. Mr. Denny's average consumption of gas for two asbestos gas fires is given at $21\frac{1}{2}$ cubic feet per hour.

T. Fletcher (of Warrington) says that gas fires cost from 1*d.* to 4*d.* per hour, but quotes no experiments to show this.

* "On Cooking and Heating by Gas."

In the gas fire of Mr. Hislop, mentioned above (see Fig. 237), a burner of fire-brick, Fig. 238, is used, which is stepped and perforated with holes of different dimensions at each step. This burner is placed in the bottom of an ordinary grate, the gas and air being admitted to it by means of a so-called

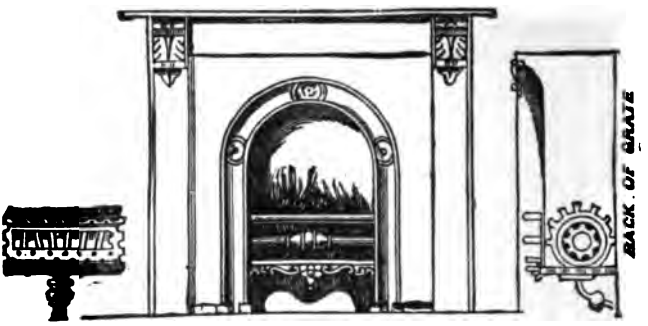
Fig. 238.



"Bunsen mixer," and the fire-place is filled up with asbestos, metal chains, or light hoop iron, which become red hot and radiate heat. The burner also becomes hot and heats the gas and air previous to combustion, so that a good temperature is kept up by this fire.

Messrs. Verity Bros. (of London) use a fire-brick burner of a different form, shown in Fig. 239, and seem to have been very successful in introducing their gas fires.

Fig. 239.



Iron burners have been proposed by Wright (of Birmingham), but they do not offer the advantages possessed by the fire-brick arrangement.

With any arrangement of open fire-place, it is, however, impossible to realize a thoroughly satisfactory result with gas fires. The same quantity of gas if burned in a good stove would produce very much better results.

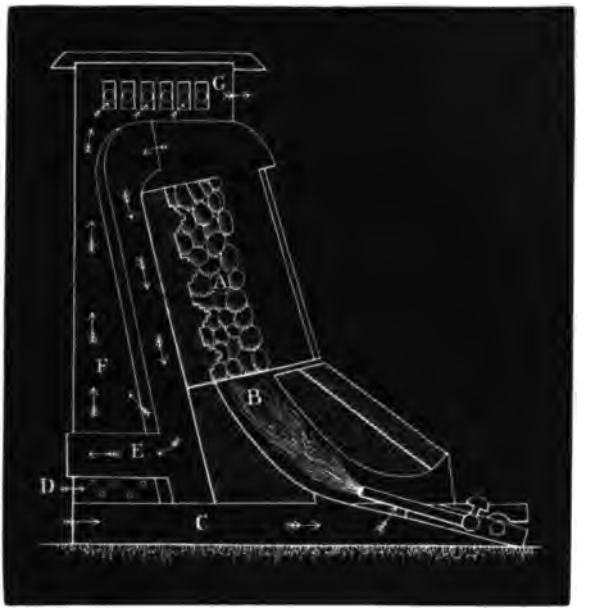
An ingenious form of gas fire has been designed by Mr. W. Foulis,* of Glasgow, for which it is claimed that it is more economical than other gas fires. From the illustration it will be seen that although this appliance is called a "regenerator gas fire," it is really a gas stove with an incandescent front, or a combination of gas fire and stove. Its design is very good, and there seems to be no reason why it should not prove to be an economical method of heating. In the papers describing it, however, no figures are given from which its performance may be compared with that of other gas stoves.

Fig. 240 illustrates this stove, in which A is the incandescent fire-brick,

* See "Proc. Phil. Soc. Glasgow," vol. xviii. pp. 365–368.

B the combustion chamber, C the chamber for heating the air-supply to the burners, D the cold-air inlet, E the flue to chimney, and F the chamber for heating the air, which escapes into the room by the outlet G.

Fig. 240.



Stoves.—Chamber stoves are constructed to disseminate heat by the direct contact of air with the heated surface, which is obtained by burning fuel on a grate, closely surrounded on all sides, except below the bars, by a good conducting or absorbing material. The most important part of the stove, which is entirely absent in the common open fire-place, is the chamber or series of flues through which the smoke passes, and which, becoming heated, communicates this heat directly to the air. The communication between the chimney and the hot chamber of the stove is generally effected by means of sheet-iron pipes, which also aid in the dissemination of heat. In the greater number of dwelling-houses, the chimneys used to be wide enough for a man to ascend them for the purpose of sweeping, and exceeded the proper dimensions for providing a draught; they thus only served to carry off the smoke, and the draught was produced by a smoke-pipe. This pipe ascending in the room, and surrounded by air, was viewed as a continuation of the hot chamber, and added very much to the effect produced by the latter. On the other hand, in many modern houses, from motives of economy, the chimney is made so small that there is not sufficient draught to make the fire burn briskly. The hot-air chamber of stoves should be correctly proportioned to the quantity of fuel consumed; it must also vary with the size of the room and the loss of heat from ventilation and radiation through walls and windows. The materials used for the construction of stoves are cast iron, sheet-iron, bricks, and tiles, and, in order to calculate the requisite amount of surface, it is necessary to know the relative degree of facility with which these communicate the heat they receive. We know, from daily experience, that iron conducts and communicates heat much more readily than clay. This power of communicating heat depends, first, on the conducting power of the material, which, according to Despretz, is

nearly 33 times greater in iron than in clay, and, secondly, on the nature of its surface,* for the heat has to be communicated not only from particle to particle throughout the material of the chamber, but also from its surface to the air, and this is partly effected by contact and partly by radiation, the different surfaces acting very differently in this respect. The communication of heat from the surface to the air, by the joint effect of radiation and contact, is, according to Péclet, in sheet iron 1.21 times, and in cast iron twice, as rapid as in clay. Iron stoves, therefore, both heat and cool more quickly than stoves constructed with bricks or tiles, and the latter must present a much larger surface than the former in order to produce an equal effect.

When the fuel is rapidly burnt in a stove, so as to evolve at once the entire amount of heat it is capable of affording, the temperature produced is far greater than is required. Iron, therefore, which conducts and evolves heat almost as rapidly as it is received, is not an appropriate material for communicating a uniform temperature of about 68° F., as required in a dwelling. Clay is decidedly preferable, for, with whatever degree of rapidity its temperature is raised, it evolves the heat much more slowly and gradually. The bricks and tiles prepared from clay amass or accumulate heat, and evolve it in a very regular and gradual manner, which renders them peculiarly well adapted for the construction of stoves. It is often objected to iron stoves that they occasion an unpleasant smell in the room, and produce headache and other disagreeable sensations. The smell is chiefly produced when some portion of the stove, by want of attention, is allowed to become red hot, and the particles of dust always floating in the air, coming into contact with the red-hot surface, are charred or burned; some slight smell, however, is said to be produced by the iron itself. The researches of Deville and Troost on this subject have demonstrated that iron when hot permits the passage of carbonic oxide, and probably of other gases, through it, and it is likely that the disagreeable effects referred to are traceable to this cause. If water is not placed on a stove which is liable to be strongly heated, the air is warmed without acquiring an amount of moisture commensurate with its increased temperature, and will then exert a drying action on the skin and all bodies exposed to it; to this action, the unpleasant sensations may in part be ascribed.

In this country, and in many parts of the Continent, and in America, iron is the material almost universally chosen for the construction of stoves, chiefly on account of its comparative cheapness and durability and the facility which it affords for the manufacture of portable stoves on a large scale. Stoves constructed of Dutch tiles or clay are extensively used in Russia, Sweden, and the central parts of Europe; in these, the heat accumulated during the combustion of the fuel is gradually given off to the surrounding air. Clay stoves are necessarily much more bulky than those made of iron. From the given quantity of air (= A) which the stove must hourly heat (to t°) to make up for the loss by cooling and ventilation, the corresponding amount of clay surface may easily be calculated. The mean weight of 1 cubic foot of clay is 62 lbs.; 1 cubic foot of air, at 68° F., weighs 0.037 lbs., therefore, 1,680 times less than an equal bulk of clay; the same amount of heat produces the same rise of temperature in equal masses of both bodies, the specific heat of air and of clay being nearly $\frac{1}{4}$th that of water. The heat, therefore, required to raise 1,680 cubic feet of air to the desired temperature, or t° above the external air, will be sufficient to produce the same effect in 1 cubic foot of clay. The latter, however, becomes much

* Péclet has corroborated this statement by experiments, according to which plates of 1 square metre surface and 1 mm. thick, at a temperature of 1° C., allow heat to pass through in the case of clay and iron as 0.24 : 7.95 = 1 : 33.1.

hotter by the action of the fire, and warms the air of the room by cooling gradually from a maximum temperature = T° to a temperature t^1°, which is still sensibly higher than t°. The heat evolved during cooling will warm a greater body of air to t° in the ratio of t° : (T − t^1°), whence we obtain $Q = \frac{A\ t^\circ}{(T - t^1)^\circ\ 1{,}680}$ as the volume of clay corresponding with the body of air to be heated.

In stoves of the simplest construction, the fire is surrounded directly by the surface to be heated, which, being placed unprotected in the room, radiates heat and warms the air by direct contact, the smoke passing away through a pipe into the chimney. The greater part of the heat communicated is in this case due to radiation, and the direction in which the pipe carries away the smoke and heated air, whether it be placed perpendicularly above the fire, horizontally, or in a downward direction before entering the chimney, is not of material consequence as far as the actual amount of heat evolved is concerned, provided the same extent of surface is exposed and a proper draught secured. The material of which the stove and the smoke-pipes are composed will of course have considerable influence on the amount of heat evolved. The pipes should be of somewhat less diameter than the minimum diameter of the chimney, not sufficiently extensive to cool the smoke too much and thus endanger the draught, nor too contracted to evolve it at a higher temperature than is required, and so cause a loss of heat: from 4 to 8 inches diameter, according to the amount of fuel to be consumed, are the most convenient dimensions.

The relative heating surface required for any given space or known amount of cooling action may be calculated approximately for practical purposes from the facts established by Péclet, that a square foot of sheet iron, freely exposed to the air, will evolve, by the joint action of radiation and contact, about 160 to 200 units of heat per hour; a square foot of cast-iron, from 400 to 500; and bricks or tiles, $\frac{4}{10}$ths of an inch in thickness, from 150 to 180, supposing the combustible to be consumed in such a manner as to exert in each case 0.8 of its heating power. General Morin, who made many investigations in connection with this subject, advised that a stove to be used for heating should have at least 6 square feet of *effective* heating surface for every 1,000 cubic feet of space to be heated and ventilated by it.

The common metal stoves frequently employed in halls, churches, and other public buildings in this country are of simple construction, and are very liable to be overheated when not properly managed. They then give rise to the unpleasant sensations above described; and even when carefully tended, so that no perceptible smell or noxious vapour is evolved, are seriously objected to by many who have been accustomed to the direct heat of an open fire. Whether this antipathy to stove heat arises merely from prejudice, or a really different effect is produced on a sensitive human body by the rays of lower intensity and less refrangibility which emanate from heated iron, it is at present impossible to decide.

A detailed description of the simple stove is quite unnecessary, nor will our limits admit of more than a few illustrations of the almost innumerable methods which have been resorted to by different inventors for economizing the heat from the stove and adapting it to different kinds of fuel. As a very economical and, when properly managed, convenient modification, we may mention the stove of Dr. Arnott, a sectional drawing of which is shown in Fig. 241. *G* is the outer iron case of the stove, *H* the inner case, lined below with fire-clay *J*, where the fuel is incandescent, above which is placed a cylindrical box or reservoir *I* of fuel. The space *N* between the outer and inner case is filled with sand as high as the valve *K*; the outer case is covered at the top by a lid fitting into a groove in the case *B*, into which

fine sand is placed, to form a smoke-tight joint. A vessel for containing water is inserted into a groove in the lid in a similar manner. *P* is the ash-pit, *O* the ash-pit door, and *L* an aperture for a regulating valve. The fuel *F M* is introduced through the lid of the inner case *C*, also secured by a sand-groove. *Q* is the grate, cast in one piece and movable on a hinge, but kept in its position by a leg *R*, which, when pushed back, allows the grate to fall, and discharge the ashes from the fire-box into the ash-pit. The fuel employed is coke or anthracite coal, broken into pieces the size of a hen's egg. In lighting the fire, some paper and dry wood, with a few house cinders, are introduced from above into the fire-box, the grate having been previously cleared of ashes; the top is then closed and a lighted paper applied below the fire-bars. When the cinders are ignited, the ash-pit door is closed, so that the air only finds admission through the valve at *L*; the whole fire-box is then filled up with fuel by means of a funnel, which single charge lasts for twelve hours. The use of the small valve at *K* is to increase the draught when required; on drawing out the stopper, air enters, and, becoming warm by contact with the inner case, escapes to the chimney. A regulating valve, shown in Fig. 242, is fitted to the aperture *L* of the ash-pit; it consists of a frame *G K C I* nicely balanced and turning with the slightest force upon a centre at *H*; a steelyard is attached to it at *H*, in which are several holes for the insertion of the small pin-weight *F*. This pin-weight is in fact the regulator of the quantity of air that enters the ash-pit. If it be removed altogether, the tendency of the air-current will be to force the discs *C* and *I* against the apertures to the left of them in the drawing, when no air will be admitted. If the weight is placed as shown in the drawing, a certain quantity of air only can enter, but on the draught of the chimney increasing, *C* and *I* will be forced to the left, and will immediately lessen the aperture and check the draught. *D* is a screw-nut for balancing the valve, *E* a cap for adjusting it without removing it from its position.

Fig. 241.

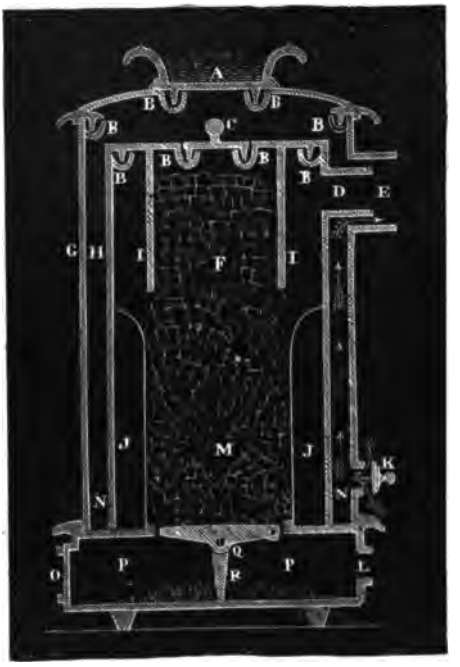


Fig. 242.

In these stoves, which burn very little fuel and in which the combustion proceeds very slowly, there is some fear of carbonic acid, on account of its great density, finding its way into the room from the ash-pit door. Dr. Ure states that this invariably occurs when the body of the stove is not heated

above 250° to 300° F. Although the common fault of stoves consists in a wasteful consumption of fuel with a tendency to overheat the air, an error may be committed in the opposite direction by a too languid combustion, when the chief product is carbonic oxide, which, passing to the chimney unconsumed, involves a loss of a great part of the heating power of the fuel.

American Stoves.—In a great part of the United States, the fuel employed for heating apartments is anthracite, which does not burn freely in an open grate, in consequence of the cooling action exerted by the large quantity of air necessarily admitted to the fuel. The conditions required for burning anthracite are a close grate, to which there is only a very limited supply of air brought in contact with the burning fuel with a considerable velocity. So liable is an anthracite fire to be extinguished by sudden cooling, that it is found more advisable to feed the fire from above than from the side by a fire-door, as is usual in other stoves, and, in consequence of this, the grates require to be of a peculiar construction, capable of being agitated or moved from the outside, so as to free them from clinkers and ashes. In Nott's stoves, the grate-bars are curved, so as to form together three parts of a cylinder, and firmly attached to side-plates, so that the whole grate can be moved by a handle outside the stove, round an axis to which the side-plates are fixed. One-third of the convex surface of the grate-cylinder is required as a support for the fuel; by means of the handle, the other two-thirds can be alternately brought to occupy its position, and by this rotating motion the ashes are caused to fall through the bars.

In Spoor's stove, also much used in America, the hot gases are made to traverse the sides of the stove in an upward and downward direction before escaping into the chimney, and the grate is of the usual circular form, but capable of being turned on a centre by a bent rod from the outside; by the motion thus communicated, the ashes are removed. Olney's stove, shown in Figs. 243 and 244, resembles in general outline that of Nott, with the

Fig. 243.

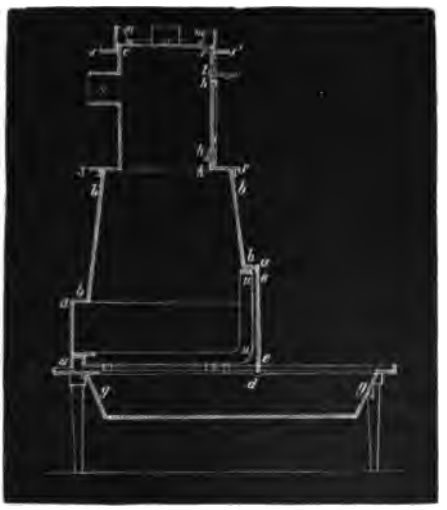


Fig. 244.

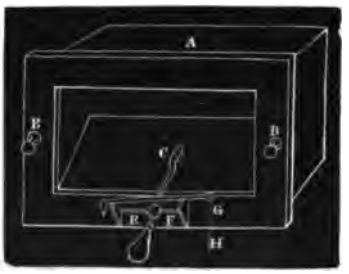
exception that the escape for the gases is confined to one aperture, whilst in Nott's there are two, at different elevations above the grate. The grate is fixed, the bars being bent at a right angle, as shown in Fig. 245 and placed parallel with each other so as to form the bottom and front of the grate. Fig. 244 shows a front view of the stove, and Fig. 243 a lateral section.

The stove is constructed in three compartments, one above the other; the lowest, *a a a a*, is lined with brick, and contains the grate, the bars rising in front to about ⅓rd of the height of the second compartment, *b b b b*. The front grate bars are shut in by an iron door *e e*, which can be lowered so as to lie flat on the covering to the ash-pit *g g*, by a kind of hinge at *d*. The middle chamber tapers slightly towards the top, and supports the upper compartment, *c c c c*. Fuel is introduced through a side door *h h* (Fig. 243), while the smoke and heated gases escape by the pipe *s''*. The ash-pit *g g* is in the form of a drawer, which slides in and out. The top of the stove *m m* is also movable, and a vessel containing water is usually placed upon it. The grate is cleared in this stove in the usual manner, by means of an iron rod.

Fig. 245.

In some stoves, the heating surface is surrounded by an outer casing, open at the top and bottom, through which the air of the chamber or air from the outside is caused to circulate and become warmed in its ascent. In others, the smoke-pipe is constructed so as to ascend and descend several times, each bend being surrounded by an open casing of this kind, by which means a very rapid current of air round the heated surface is produced, and the smoke is more perfectly cooled, while the same amount of radiant heat is evolved. When the air circulating through these outer casings is supplied from without, and the fireplace of the stove is also on the outside of the apartment, the current thus produced will ventilate the room, provided some means of escape is afforded for the warmed and vitiated air, either into the open air or, by means of a valve, into the chimney. The valves invented by Arnott are well adapted for ventilating such apartments. They consist of a box *A*, Fig. 246, let into the wall, just below the ceiling and opposite the chimney flue, into which an opening is made, corresponding with that in the box; *C* is the valve, accurately balanced by a projecting weight, moving on a hinge at *E F* and fitted to the aperture in the box in such a manner that, although the warm current of vitiated air, pressing it inwards, can escape without difficulty into the chimney, yet if there is the slightest downward current of smoke from the chimney the valve will at once shut. *H* is a string attached to a spring lever at *G*, by means of which the valve can be permanently closed.

Fig. 246.

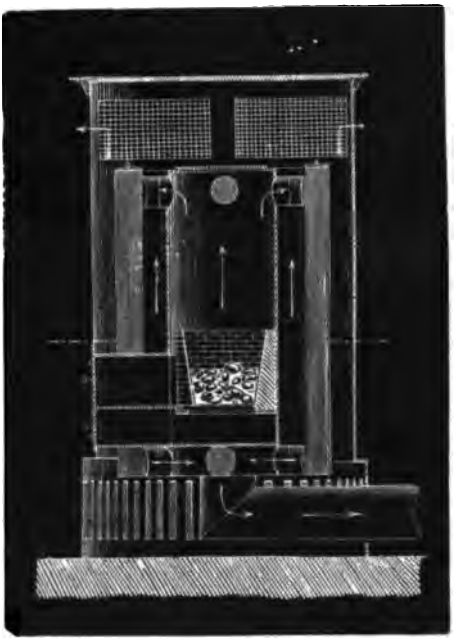


A metal stove constructed on this principle is shown in Figs. 247 and 248. The fire-place, being intended to consume coal or anthracite, is constructed of bricks; the smoke and heated gases, ascending immediately above the fire in a single flue, descend again through several passages, as indicated by the arrows, and pass off through a common flue under the floor to the chimney. The air of the apartment, entering at the bottom of the stove below the fire-place, circulates round the flues, in a contrary direction to that in which the smoke is escaping, and is discharged through a wire grating surrounding the whole of the upper part of the stove.

A similar arrangement is sometimes adopted with the flame reversed. The grate is then placed in the central or upper part of the stove, covered above with a perforated lid, through which the fuel is introduced, and the air enters for supporting the combustion; the smoke traverses two concen-

tric flues, with internal projections, in an upward direction in the one, and downward in the other, before escaping through an underground flue to the chimney; the air of the room, entering below, ascends in contact with the outer concentric cylinder. The grate and smoke-flues, arranged in this manner, are speedily destroyed, and it is always necessary, before lighting the fire in the stove, to create a draught by heating the chimney.

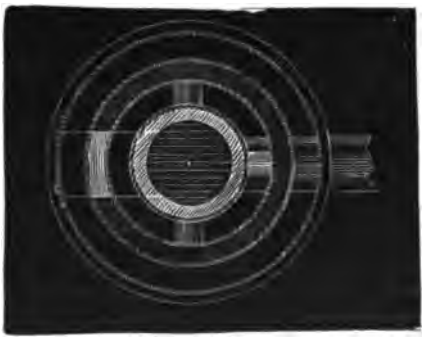
Fig. 247.



The smoke-pipe from a stove sometimes passes through a cast-iron vessel, filled with water, which, becoming heated, forms a hot-water stove, retaining a moderate heat for a long time.

In order to obtain the greatest amount of heat from the flues or pipes conveying the hot gases from a stove, it is more economical to surround them on the outside with pipes for the passage of the air to be warmed, than to allow the air-pipes to traverse the flues. In the former plan, the smoke is cooled more effectually, and the radiant heat, although in somewhat diminished quantity, is communicated from the inner to the outer envelope, and thence to the room; in the latter arrangement, the heat radiated to the air-pipes is almost entirely lost, passing from one side of the pipe to the other without warming the air in its passage; the air, however, being more strongly heated by conduction, the rapidity of the current is increased, which may, under some conditions, compensate for the loss of radiant heat. Much of the radiant heat may also be economized by placing solid bodies in the interior of the passages, which become heated, and communicate this heat to the current of air by contact with it; lateral projections in the direction of the tubes, which do not interrupt the passage of the air, are best adapted for this purpose. The smoke-pipe from a stove should always ascend for some distance above the fire, in order to secure a draught; it should never be subdivided in its upward course, as a slightly stronger upward draught in one of the passages will cause a downward current in the others. When the current has a downward direction, this cannot occur, and the smoke will traverse a number of flues simultaneously.

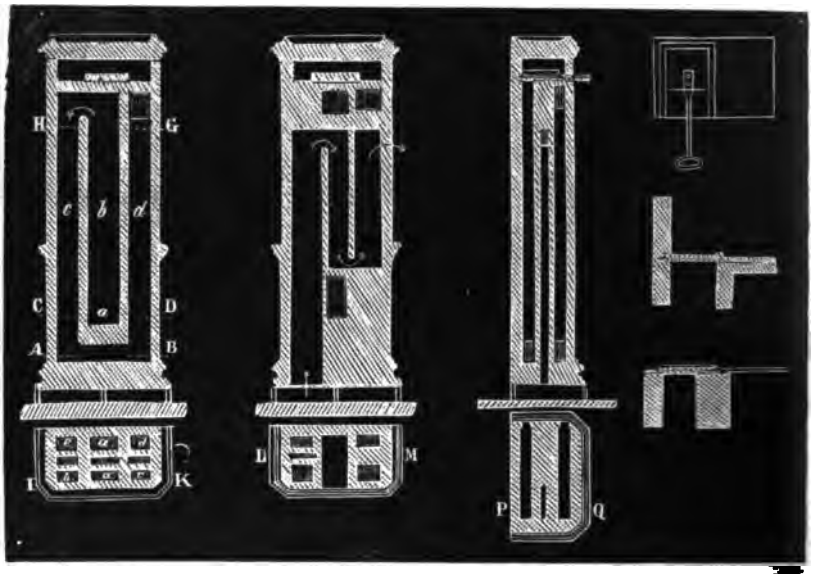
Fig. 248.



In many continental countries, iron stoves of simple construction are still very generally used. Sometimes an iron stove is surmounted by a series of

clay flues, through which the smoke and heated gases pass, a portion of their heat being stored up by the body of the clay, and afterwards communicated slowly to the surrounding air. In other cases, the whole body of the stove is constructed of clay and frequently encased with porcelain tiles, forming an ornamental structure in the room. The fire-door is often placed in the corridor, when, air from the room not being required to supply the oxygen for combustion, no draught is occasioned, and the air, being stagnant, soon becomes vitiated, unless some special means for ventilating the room is introduced. A current of air is sometimes allowed to circulate through channels running parallel to the flues, entering below and passing out warmed at the top of the stove. A stove of this description is shown in Fig. 249, where 1

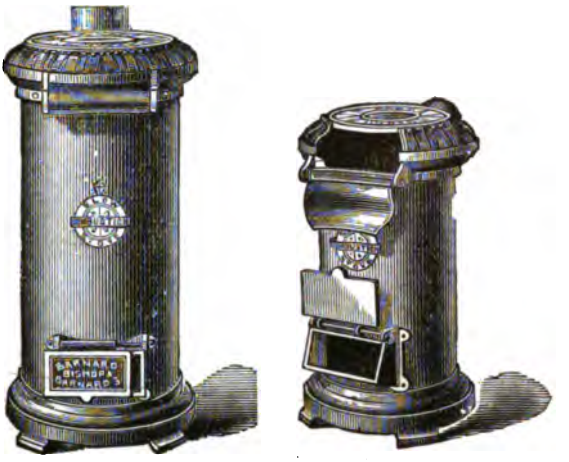
FIG. 249.



represents a vertical section on the line *I K* (2); 3, a vertical section in direction of *L M* (4); 5, a vertical section in the direction of *P Q* (6); 2, 4, 6 are horizontal sections in the direction of the planes *H G*, *C D*, and *A B*; 7, 8, and 9 represent the details connected with the damper. The air-channel and the direction in which the air travels are shown in 3; on each side of this channel, the smoke-flues *b c d* convey the hot gases from the fire at *a*, which after traversing the body of the stove as indicated in 1, unite at the top before entering the chimney. Wood is generally burnt in these stoves, on a simple hearth, without a grate; a brisk fire is kindled with about 1½ cubic feet of beech-, birch-, or pine-wood, which is soon consumed. When the flame is extinguished and the embers are still glowing, the damper is closed above and the ash-pit and fire-door below, to prevent any further flow of cold air through the stove into the chimney; the heat accumulated in the body of the stove is then slowly given off to the air of the apartment.

Fig. 250 illustrates a simple form of cast-iron stove for coke fuel which is largely used. It consists of a cast-iron cylinder, made of various sizes, according to the heating power required, and lined with fire-brick. The opening at the top is for charging the stove with fuel, and the lower one is under the level of the fire-bars, and is used for removing ashes. This stove heats simply by radiation, and allows the heated products of combustion to escape directly upwards to the chimney.

Fig. 250.



The stove introduced by the late Mr. J. R. Napier, F.R.S. (Figs. 251 and 252), was designed to economize solid fuel, and has arrangements by which the hot gases are made to descend before entering the chimney. This principle of conducting the gases downwards before they are allowed to escape is

Fig. 251.

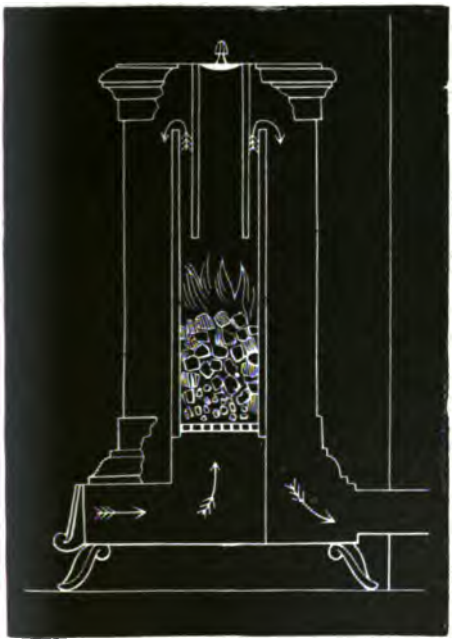
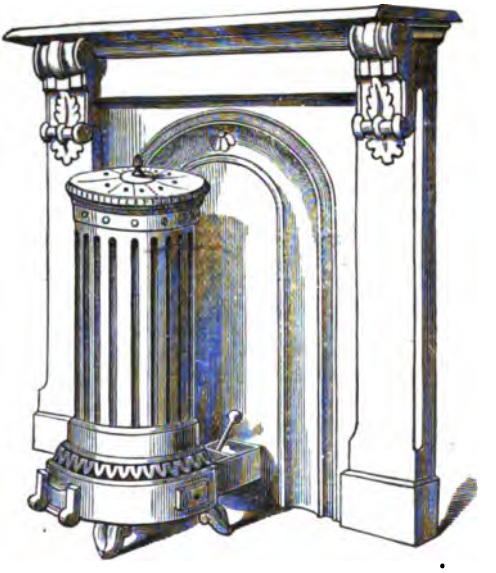


Fig. 252.



scientifically correct, because the heavier or cooler gases escape first, the hotter gases being kept longer in contact with the radiating surfaces of the stove. Better diffusion of the hot gases is also obtained in this way.

Many experiments were made with this stove by Mr. Napier, and formed

the subject of a communication* to the Philosophical Society of Glasgow. He found that one of these stoves, having about 24 square feet of heating surface, in a room of about 5,000 cubic feet capacity, by burning 1 lb. of gas coke per hour for ten hours per day, kept the room as fresh as, and fully hotter than, about 30 lbs. of the same coke burned in one of the isolated American open fire-places, or "American stoves," as they are called, and, as compared with ordinary open fire-places, the Napier stove was equal to a fire-place burning at least 40 lbs. of good coal.

Figs. 253 and 254 illustrate a stove for solid fuel which was brought out by

Fig. 253.

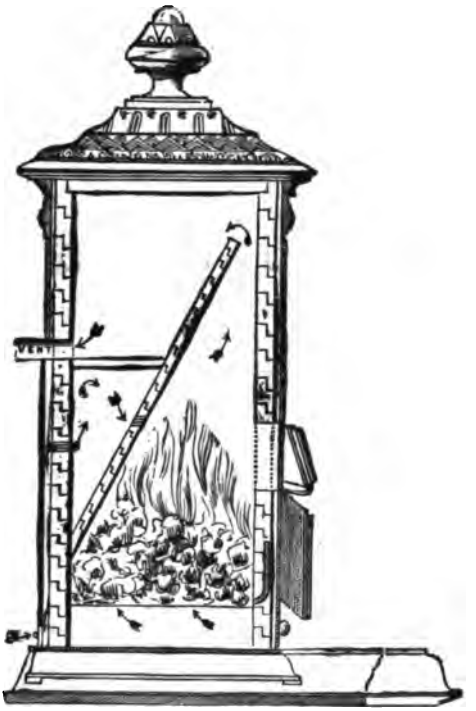
Mr. J. Dunnachie, a well-known manufacturer of fire-bricks, at the Smoke Abatement Exhibition in London in 1881. The object of the designer was to construct a fire-brick stove, as contrasted with those in which fire-brick is used only to protect certain portions of the internal surface from the action of the fire, in order to have the heat radiated from fire-brick instead of from iron surfaces into the room to be warmed. Some framework of iron was necessary on the outside to bind the bricks together, but Fig. 253 shows that for the purpose of ornamentation, or possibly of satisfying the popular taste for iron stoves, so much iron has been used as almost to completely encase the fire-brick. There is no doubt that the radiation from fire-brick surfaces is more equable and pleasant than that from iron, being more constant in amount, and free from the unpleasant odour given off by iron stoves. It is to be regretted, therefore, that in this stove the iron radiating

* See "Proceedings Phil. Soc. Glasgow," Feb. 4, 1873, vol. ix. p. 35.

surfaces are not reduced to the minimum, even although the whole internal surface of the stove is of fire-brick.

The stove is arranged with a restricted opening for the products of combustion at the top of the diagonal division so as to prevent rapid combustion, and means are provided for admitting a subsidiary supply of air at the top

FIG. 254.



surface of the fire so as to prevent unconsumed gases escaping. Experiments showed that a stove of this construction, 18 inches square and 3 feet high, would maintain a temperature of 60° to 65° F. for twenty-four hours in a room of 3,600 cubic feet capacity, with a consumption of 14 to 28 lbs. coal according as the firing was managed.

Gas Stoves.—The use of appliances for using illuminating gas as fuel in heating and cooking operations has largely increased of late years, several exhibitions of such appliances having greatly contributed to popularizing them, as well as to stimulating the introduction of improved forms. The Smoke Abatement Exhibition held at South Kensington in 1881, the International Electric and Gas Exhibition held at the Crystal Palace, Sydenham, in 1882–83, and the Exhibition of Apparatus for the Utilization of Gas and Electricity held at Glasgow in 1880, under the auspices of the Philosophical Society of that city, have been the most important, and have furnished reports on the apparatus exhibited, with tests of efficiency, which make these reports valuable works of reference. The Report on the Gas Section of the Exhibition of 1882–83, made by Messrs. F. W. Hartley, W. J. Dibdin, W. Foster, and D. K. Clark, to the committee of that section, and published by the Secretary of the Gas Institute at 22 Great George Street, Westminster, contains many details of the construction of gas-heating appliances, besides results of the careful testing of gas-burners. The question of burners

TABLE OF AVERAGE RESULTS OF TESTS OF GAS-BURNERS BY W. J. DIBDIN AND W. FOSTER.

Average Results obtained with all the Burners except Flat-flame Burners, tested under Varying Pressures, in which Cases the Maximum Result is given

Consumption, Illuminating Power, and Duty per Cubic Foot of Gas consumed, stated in Standard Sperm Candles. Corrected for Temperature and Pressure, and reduced to a Standard of 16-Candle Gas.

Description of Burner.	Rays from Burner Horizontal.			Rays from Burner 22.5° with Horizontal Line.					Rays from Burner 45° with Horizontal Line.					Rays from Burner 90° with Horizontal Line.		
	Consumption per Hour in Cub. Ft.	Disc Vertical.		Consumption per Hour in Cub. Ft.	Disc Vertical.		Disc 11.25°.		Consumption per Hour in Cub. Ft.	Disc Vertical.		Disc 22.5°.		Consumption per Hour in Cub. Ft.	Disc 45°.	
		Illum. Power.	Duty.		Illum. Power.	Duty.	Illum. Power.	Duty.		Illum. Power.	Duty.	Illum. Power.	Duty.		Illum. Power.	Duty.
Gilmston's 10-ft. recuperative burner .	8.60	45.6	5.29	8.60	38.7	4.52	44 1	5.12	8.15	20.2	2.49	34.9	4.28			
Siemens' No. 0 ditto, without reflector .	63 97	312.2	4.88	60.90	205.0	3.37	245.0	4.03	63.40	—	—	104.2	1.64	67.50	10.9	0.163
Ditto No. 1 ditto, ditto	55.75	266.2	4.77													
Sugg & Co.'s 4-ringed 400-candle argand, with reflector	94.80	451.3	4.77	96.70	453.5	4 76	519.5	5.57	96 50	282.5	2 92	491.5	5-08	100.50	567.5	5 80
Clark's 5-ft. recuperative burner . .	5.32	24.8	4.76	6.00	27.0	4.62	29.7	5.39	5.43	20.6	3.82	34.2	6.36	5.07	35.0	6.91
Douglass's 6-ringed argand, with reflector	91.40	436.3	4.71	99.60	326.0	3.27	352.0	3.53	85.70	47.5	0.50	87.3	1.02	90.20	2325.0	25.80
Lewis's incandescent 1½ × ½ inch, without reflector.	13.40	62.7	4.63	—	—	—	—	—	13.65	23.7	1.89	38.4	2.81			
Siemens' No. 2 recuperative, without reflector	29.31	132.6	4.53	—	—	—	—	—	27.90	49.4	1.77	85.8	3.10			
Clark's 10-ft. recuperative, with reflector	11 92	51.1	4.29	10.86	62.8	5.72	68.8	6.33	10.04	42.5	4.25	67.1	6.67			
Clamond's incandescent, without ditto .	7.69	32.7	4.26	7.50	26.5	3.54	30.8	4.13	7.54	15.6	2.07	25.2	3.35			
Sugg & Co.'s 2-ringed 100-candle argand, with reflector	28.50	120.8	4.25	—	—	—	—	—	30.20	81.0	2.68	136.5	4.53	97 55	97.5	3.55

Grimston's 25-ft. recuperative	27.40	108.3	3.96	27.37	140.5	5.13	162.2	5.92	26.45	124.1	4.48	186.9	7.07	28.50	244.0	8.56
Douglass's 3-ringed argand, without reflector	21.60	85.1	3.93													
Lewis's incandescent 1 × ½ inch, without reflector	13.80	52.1	3.77													
Sugg & Co.'s 3-light 100-candle Lambeth, with reflector and opaque base	28.30	98.0	3.76	—	—	—	—	—	27.30	104.2	3.82	161.9	5.93	27.80	39.7	1.43
Greene & Son's double-chimney recuperative argand, without reflector	3.80	13.7	3.03													
Sugg & Co.'s J argand, with centre jet, without reflector	8.60	31.0	3.63	—	—	—	—	—	8.30	15.7	1.92	25.1	3.03			
Ditto 3-light 100-candle Lambeth, with reflector and glass base	27.30	93.8	3.43	—	—	—	—	—	27.60	88.2	3.20	144.0	5.21	27.60	80.1	2 91
Ditto K argand, with centre jet, without reflector	8.88	29.6	3.43	—	—	—	—	—	8.40	14.5	1.72	25 7	3.06			
Ditto D argand, with centre pin, without reflector	4.45	14.9	3.35	—	—	—	—	—	4.30	9.2	2.14	12.7	2.96			
Ditto 5-light 150-candle Westminster, with reflector	45.30	151.5	3.35	—	—	—	—	—	42.70	129.3	3.04	207 0	4.86	42.00	125.2	2.98
Ditto B argand, plain, without reflector	3.55	11.8	3.33													
Brönner's No. 5, with B top flat flame, without governor	6.20	20.0	3.23													
Sugg & Co.'s 7-ft. table-top flat-flame lamp burner, with governor	8.00	25.6	3.21													
Ditto 10-ft. ditto, ditto	9.30	29.7	3.20													
Ditto 10-ft. ditto, without ditto	10.00	31.6	3.16													
Ditto E argand, with centre pin, without reflector	4.80	15.0	3.13	—	—	—	—	—	4.80	9.05	1.90	12.6	2.63			
Ditto 10-ft. table-top, with adjuster	10.70	33.3	3.11													
Greene & Son's 3-light street lamp, with reflector	21.45	65 2	3.06	—	—	—	—	—	22.75	52.2	2.33	86.5	3 90	21.60	105.5	4.97

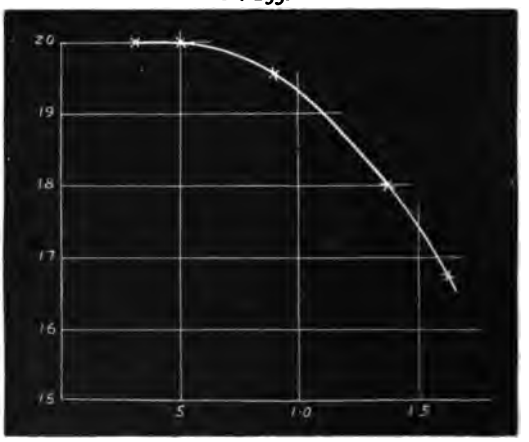
really contains the key to the whole subject of the use of gas for heating as well as for lighting.*

In fact, light-giving and heat-giving qualities are very closely allied, and for some kinds of apparatus (where, for instance, radiant heat is required) are identical, although this does not seem to have been always recognized. Probably, in the future, more will be done with burners of the incandescent type used in heating appliances.

On account of the value of these tests, and of the importance of accurate information on this subject, we have inserted at pp. 414, 415, a table giving the average results obtained by Messrs. Dibdin and Foster in their trials of different forms of burners.

The following table and diagram (Fig. 255) are taken from Mr. W. Denny's paper, "On Cooking and Heating by Gas," as they illustrate a very interesting point. They record the results of some experiments made on the economy of burning gas for illuminating purposes at a low pressure. The curve (Fig. 255) shows the results graphically, and "they prove," as Mr. Denny says, "very clearly that the efficiency, as measured by the candle power of the light produced brought to a common consumption rate of 5 cubic feet per hour, varies in a ratio inversely to the pressure at which the gas is consumed. Doubtless a similar economical principle applies to the consumption of gas for heating and cooking purposes."

Fig. 255.



No. 5 Bray's Burner, tested at Dumbarton Gas Works, December 22, 1880.

Pressure in Inches of Water.	Consumption in Cubic Feet per Hour.	Illuminating Power in Standard Candles.	Illuminating Power with Consumption reduced to 5 Cubic Feet per Hour.
0.3	2.00	8.0	20.0
0.5	2.75	11.0	20.0
0.9	3.80	14.8	19.5
1.35	4.85	17.4	18.0
1.6	5.35	18.0	16.8

The illuminating power of the gas—tested under the most favourable conditions, in a large burner, No. 8. at 0.5 inch of pressure—was found to be 29.3 candles for a consumption of 5 cubic feet per hour.

Gas stoves without chimneys—that is, those from which the products of the combustion of the gas are allowed to escape into the atmosphere of the

* See also "On the Economica Combustion of Coal-gas,' 'by Dr. W. Wallace, "Proc. Phil. Soc. Glasgow,' 'vol. ix. p. 57.

room which is being heated—are fundamentally wrong, and are used only where health is sacrificed to economy of gas.

Of stoves which provide luminous flames, or a source of radiant heat as well as a supply of fresh-heated air, those of Adams and Fletcher may be

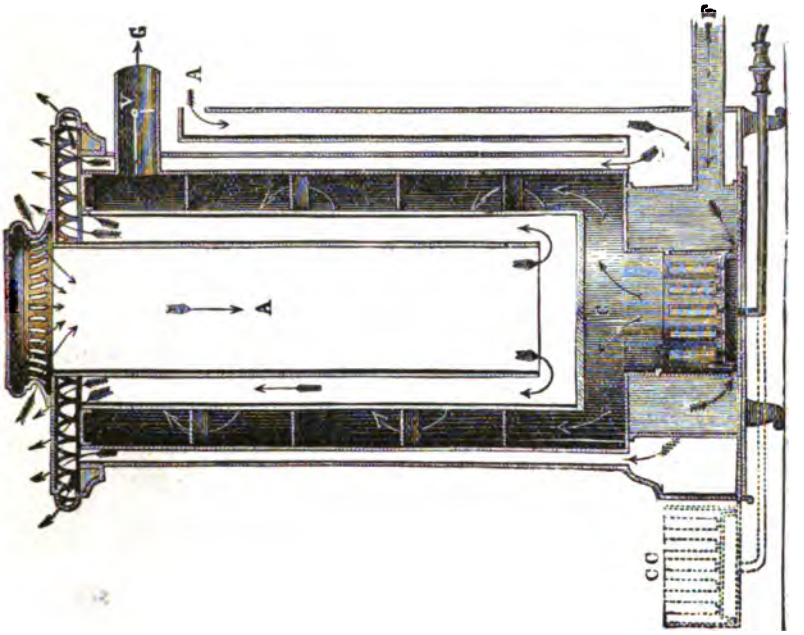


Fig. 257.

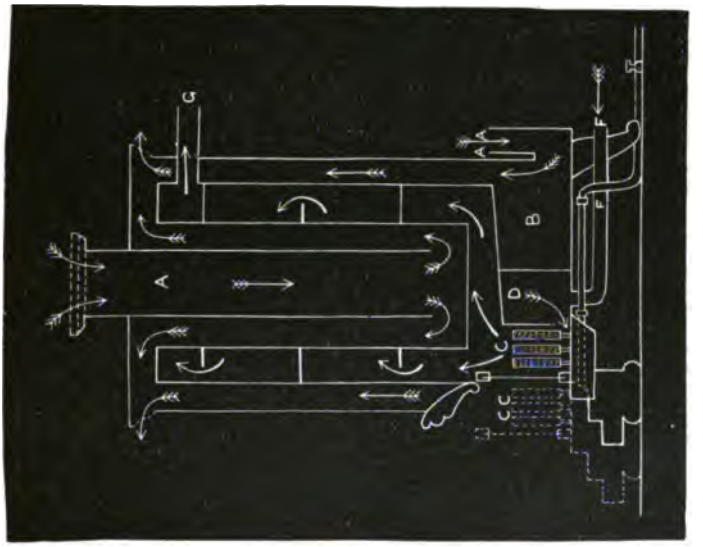


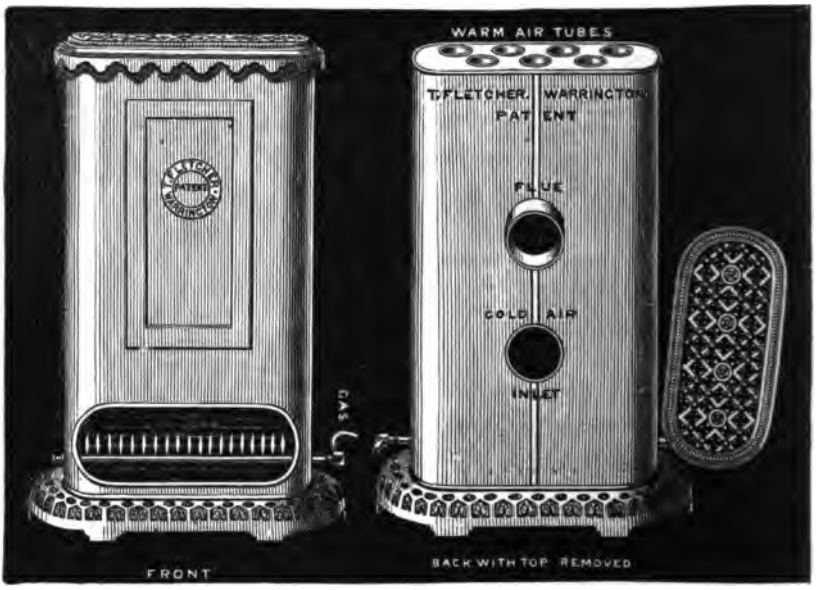
Fig. 256.

taken as examples; while of the numerous stoves which merely supply heated air, those of Wright, Dr. Bond, and Schönheyder will serve as specimens.

Gas Stoves with Radiating Burners.—In Dr. Adams' patent stove, shown in section in Fig. 256, a mixture of gas and air is burned in a series of

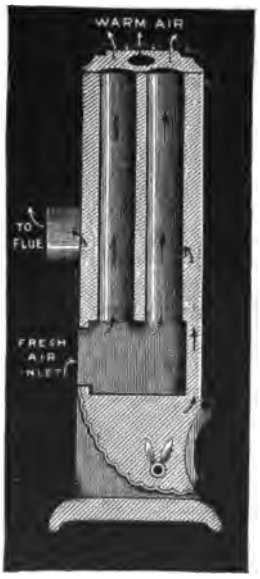
fire-clay burners, or atmopyres, similar to those first introduced in Hofmann's combustion apparatus, used in chemical laboratories. These burners, C C, are

FIG. 258



cylindrical in shape, and are pierced radially with numerous small holes, through which the gas and air issue. The burners are arranged upon a tray, which is drawn forward for lighting, so that the burners are lighted in the air outside the stove, and an accumulation of gas inside is prevented. In a very short time the burners become red hot, and a small supply of gas then suffices to maintain this temperature. Being placed behind a glass or mica panel, the radiation from the mass of red-hot brick burners is made available, while the hot products of combustion are passed over a considerable amount of surface formed by sheet-iron partitions, the other side of which is traversed by the air which is being heated. The waste hot gases are allowed to escape by a chimney G at about 240° F., this being the temperature necessary to produce an effective draught without danger of carbonic acid and carbonic oxide being returned to the chamber by regurgitation, and a supply of fresh air, which may be drawn from outside the house by the pipe A A, is heated to from 150° to 200° F. above the outside temperature, at the rate of about 200 cubic feet of air per cubic foot of gas burned per hour. The earlier form of the stove is shown in Fig. 257.

FIG. 259.

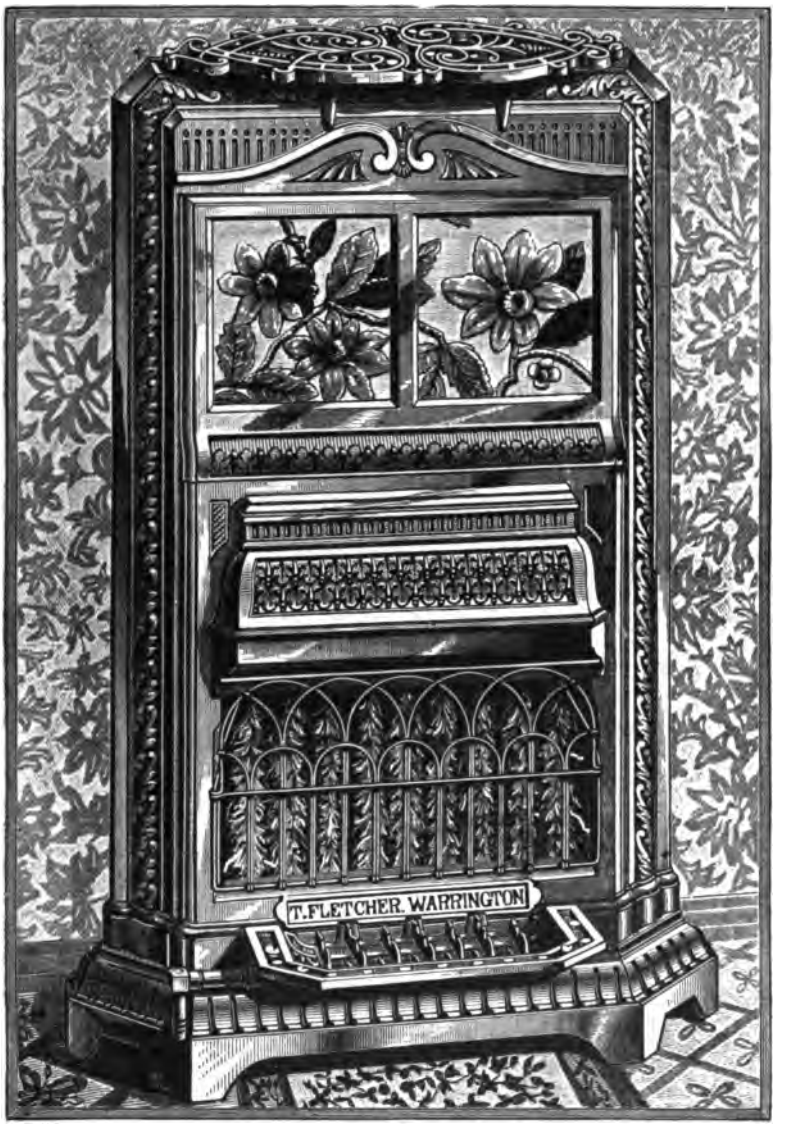


Fletcher's gas stove, or "gas fire," as he calls it, Figs. 258–260, makes

use of simple illuminating flames from ordinary burners for the supply of radiant heat, and causes the hot products of combustion to ascend in contact with vertical tubes, which are thus heated, and induce a current of air through them, the air being delivered at the top heated.

In Fig. 260 the most recent modification of this stove is represented, where

FIG. 260.



the radiant heat from ignited asbestos, or from an iron fret, seen in the lower part of the engraving, is combined with the system of warming by hot air shown in Fig. 259; the stove with asbestos is better adapted for a sitting-room.

Fig. 261 shows the external appearance of one of the ventilating gas-heating stoves made by Messrs. Wright, of Birmingham. In it, as in the

Fig. 261.

Fig. 262.

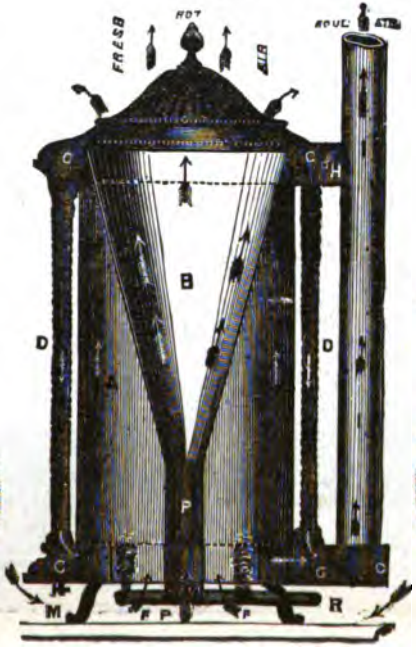


Fig. 263.

"Euthermic" stoves of Dr. Bond, of Gloucester, Figs. 262–267, the gas is admitted through a Bunsen mixer to a perforated ring burner, which is

Fig. 264.

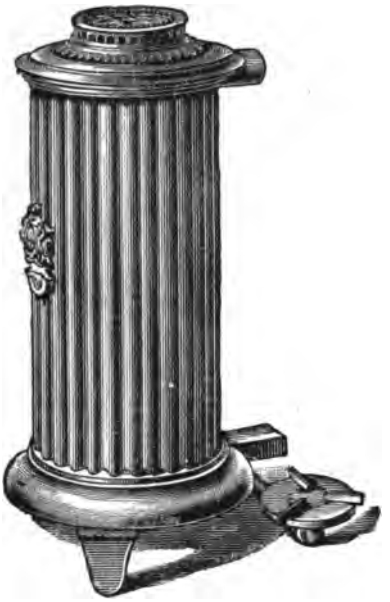


Fig. 265.

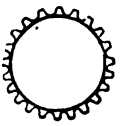


Fig. 266.

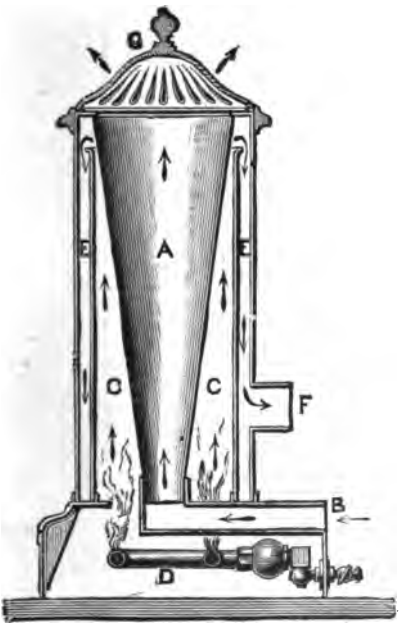
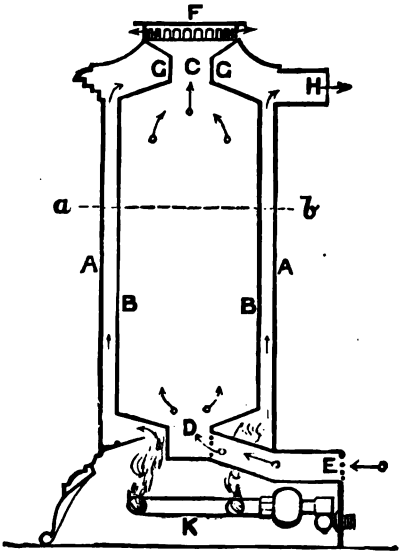
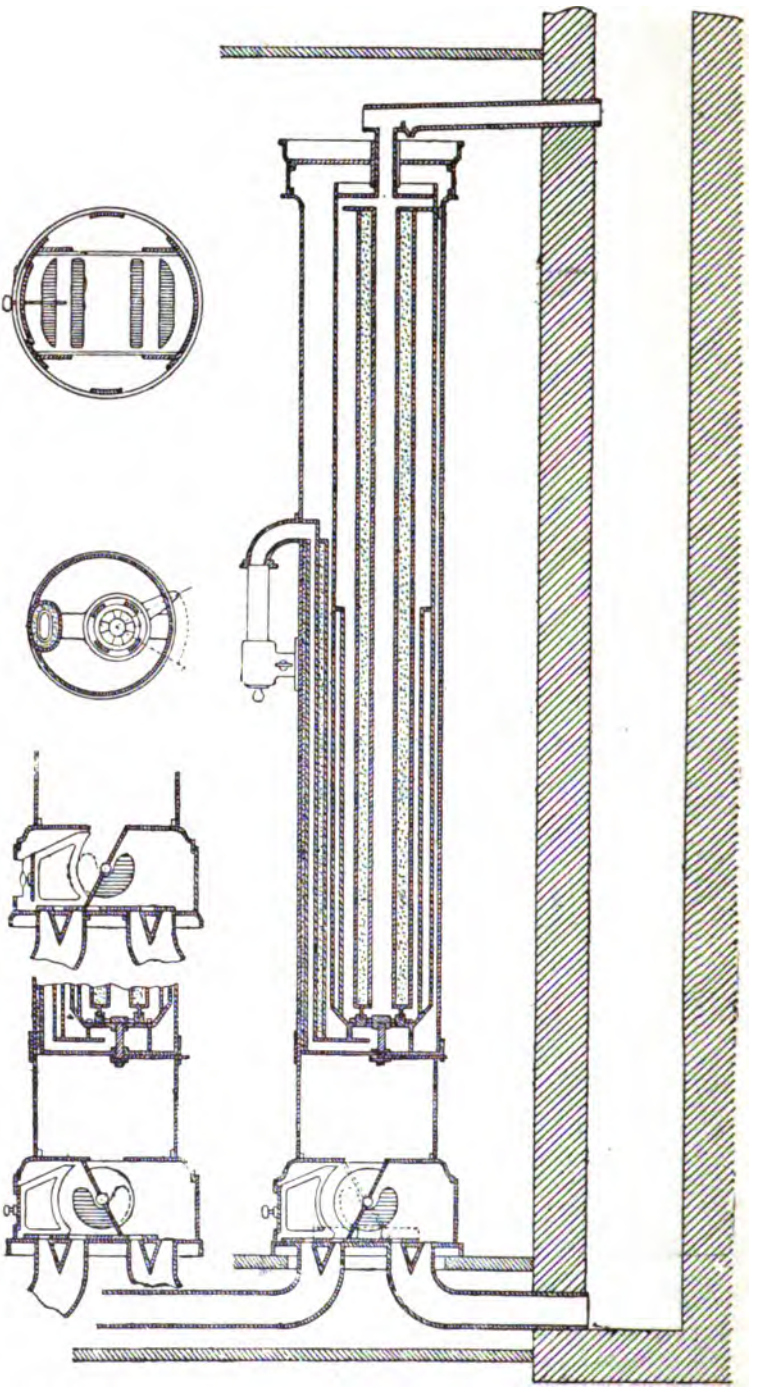


Fig. 267.

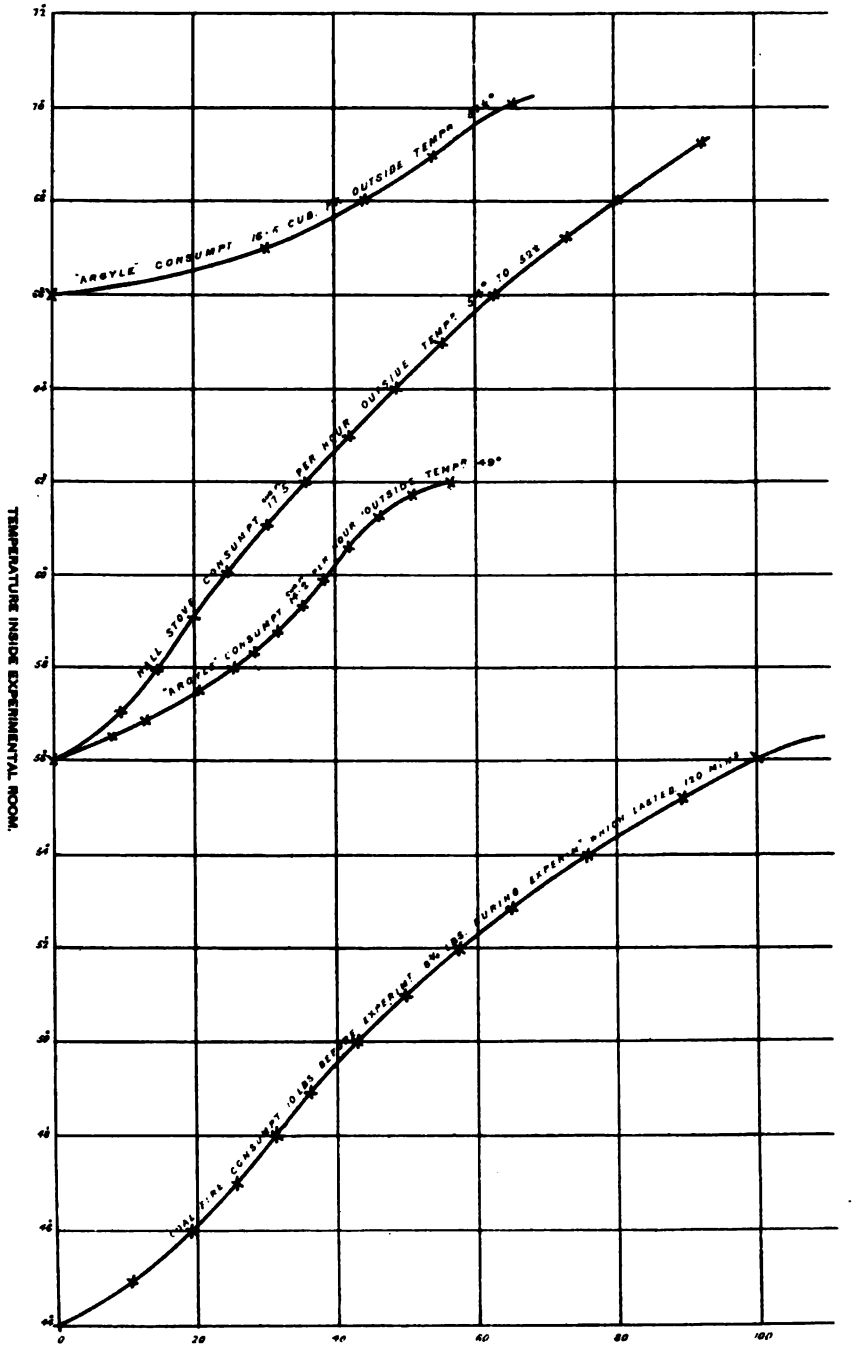


placed at the bottom of the stove and in the centre. In Wright's stove, the burner is situated a small distance from the floor within the stove, which is perhaps better than having it between the bottom of the stove and the floor,

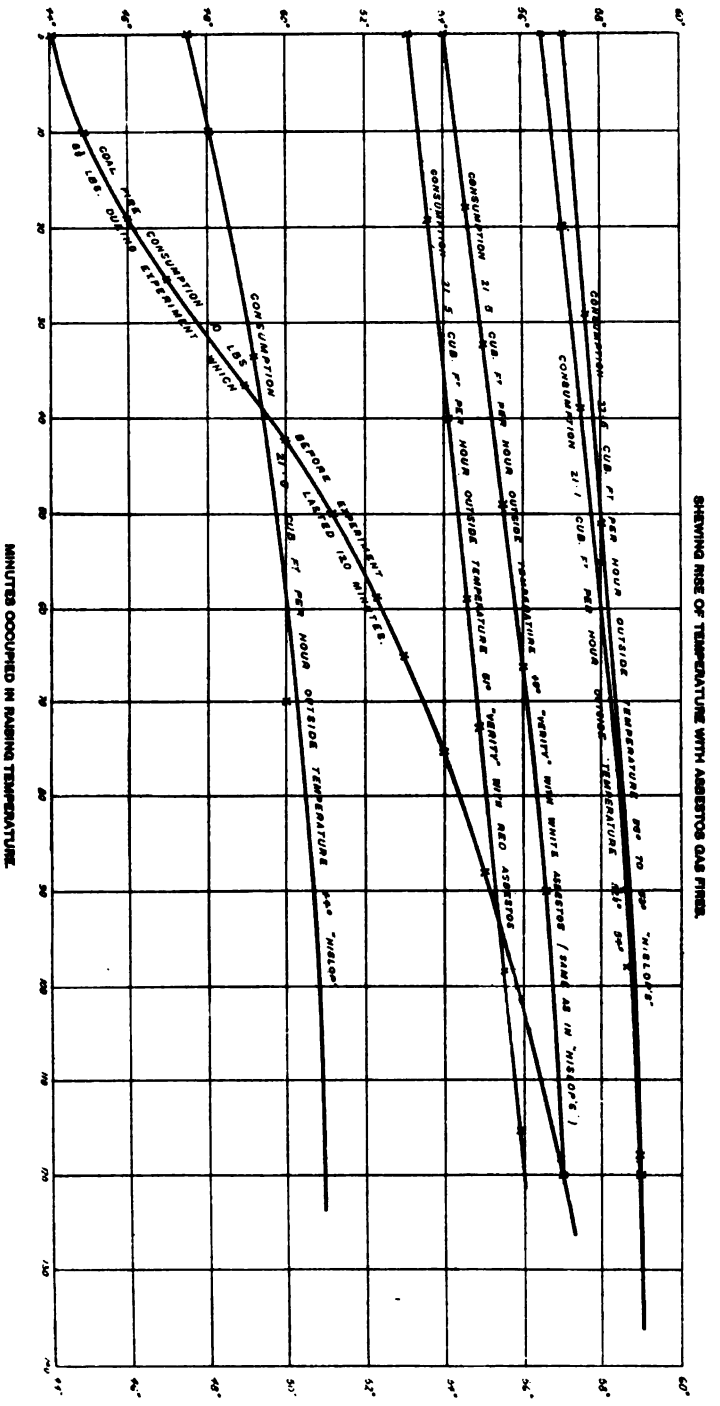
Fig. 268.



SHOWING RISE OF TEMPERATURE WITH PRODUCTS OF COMBUSTION THROWN INTO ROOM.

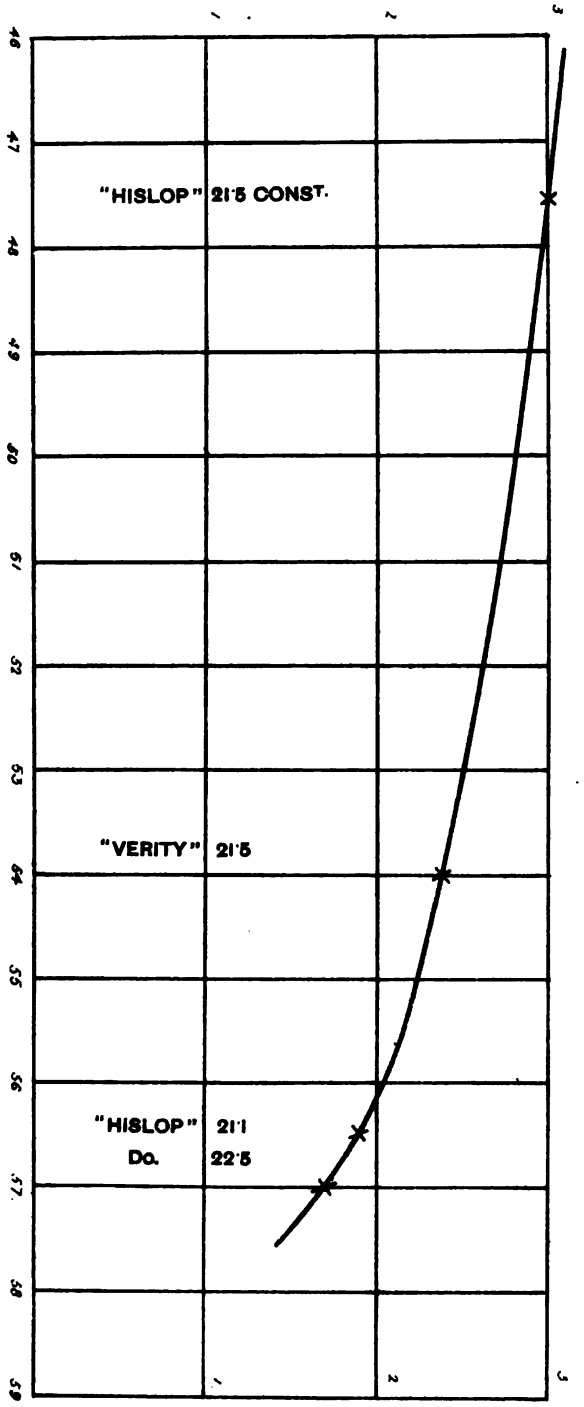

"ARGYLE" CONSUMPT 16·4 CUB. FT. OUTSIDE TEMPR 54°
PELL STOVE CONSUMPT 17·5 PER HOUR OUTSIDE TEMPR 50° TO 52°
"ARGYLE" CONSUMPT 14·5 PER HOUR OUTSIDE TEMPR 49°
MATERIAL CONSUMPT 10 LBS BEFORE EXPERIMT 9¾ LBS. DURING EXPERIMT UNION LASTED 120 MINS
TEMPERATURE INSIDE EXPERIMENTAL ROOM.
MINUTES OCCUPIED IN RAISING TEMPERATURE.

To face page 422

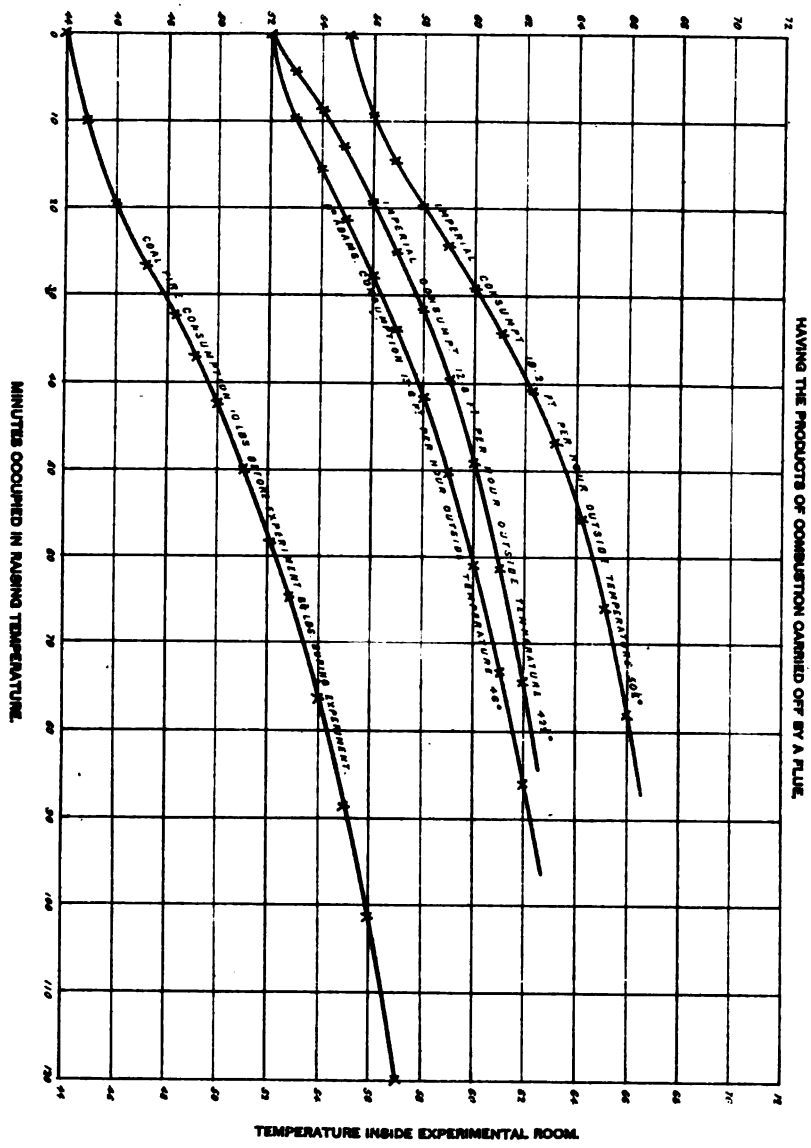

SHEWING RISE OF TEMPERATURE WITH ASBESTOS GAS FIRES.
MINUTES OCCUPIED IN RAISING TEMPERATURE.
TEMPERATURE INSIDE EXPERIMENTAL ROOM.

To follow Pl IV

DIAGRAM SHEWING RISE OF TEMPRE. FROM DIFFERENT INITIAL TEMPRES. FOR A GIVEN CONSUMPT IN WHITE ASBESTOS FIRES.



To follow Pl V


SHOWING RISE OF TEMPERATURE WITH RADIATING GAS STOVES
HAVING THE PRODUCTS OF COMBUSTION CARRIED OFF BY A FLUE.
IMPERIAL CONSUMPT. 0.5 FT. PER HOUR OUTSIDE TEMPERATURE 40°
IMPERIAL CONSUMPT. 1.0 FT. PER HOUR OUTSIDE TEMPERATURE 42°
IMPERIAL CONSUMPTION 1.5 FT. PER HOUR OUTSIDE TEMPERATURE 46°
COAL GAS CONSUMPTION 10 LBS. BEFORE EXPERIMENT 88 LBS. DURING EXPERIMENT.
MINUTES OCCUPIED IN RAISING TEMPERATURE.
TEMPERATURE INSIDE EXPERIMENTAL ROOM.

To follow Pl. VI

as in Dr. Bond's stove. The hot gases ascend in contact with a vertical air shaft B, Fig. 262, tapered outwards towards the top, and then descend through a series of small tubes D, Fig. 262, arranged round the main cylindrical casing of the stove, finally passing out by a flue or chimney I.

Dr. Bond has introduced some improvements in details of construction in his stoves, and in particular has an alternative opening to the chimney at the top of his stove regulated by a valve or damper H, Fig. 262, by means of which a much more rapid combustion can be carried on, and varying conditions of chimney draught can be met.

The stove designed by Mr. Schönheyder, Fig. 268, is of more elaborate construction than either of the foregoing, on account of its being arranged to provide means of ventilation as well as heating. The products of the combustion of one or more gas-jets, which may be luminous and set behind glass in order to give light, are conducted through passages in the stove to the chimney, the air, which is supplied from the outside of the house or building, being heated in its passage through channels formed by the heated surfaces. A valve and discharge are provided at the foot of the stove, by which the air of the room, when cooled and falling to the floor-level, can be withdrawn by the chimney; but the stove can be used for heating without changing the air of a room.

The results of comparative tests of the efficiency of these and other gas stoves will be found in the Reports of the various gas exhibitions already referred to; those carried out at the Glasgow Exhibition will be found in the tables at pp. 424, 425. Some interesting comparative tests, which included the results from an ordinary coal fire and those from gas fires, as well as from several kinds of stoves, were carried out by Mr. W. Denny,* of Dumbarton, who set out the results graphically in a series of diagrams (Plates IV. to VII.). Mr. Denny's results are given in the following table:—

RISE OF TEMPERATURE IN 80 MINUTES IN A ROOM 10½ FEET × 12¼ FEET × 11 FEET = 1,415 CUBIC FEET.

	Initial Temperature.	Rise.	Outside Temperature.	Consumption. Cubic Ft.
Waddell & Main's hall stove	56° F.	11.9° F.	54° to 52½° F.	17.5
Coal fire[1]	44	10.3	39½	—
Imperial stove	55	11.0	50½	19.2
Do.	52	10.4	42½	12.8
Dr. Adams' stove	52	9.5	46	13.6
Verity's fire—white asbestos	54	2.4	49	21.5
Do. —red do.	53	2.2	51	21.5
Hislop's asbestos fire	57	1.5	56 to 53	22.5
Do. do.	56½	1.9	52½ to 54	21.1
Do. do.	51	2.1	42	39.2
Do. do.	47½	3.0	44	21.5
Do. do.	44	4.3	36	32.2

[1] N.B.—It is to be noted that the efficiency of the coal fire in raising temperature is really lower than it appears, and very probably considerably lower, owing to the initial temperature of the room in its case being on the average about ten degrees lower than in the case of the gas fires, with which it is compared. The deductions drawn from this table in the paper are, therefore, too favourable to the coal fire.

In all these results, however, there is merely a comparison instituted between the quantities of fuel required by the various heating apparatus, and the time taken by each to produce a given rise of temperature in a room. To

* See "On Cooking and Heating by Gas," by W. Denny (J. Menzies & Co., Glasgow and Edinburgh).

TABLE OF TESTS OF GAS-HEATING STOVES

Name of Stove, with Name of Maker or Agent.	Cubic Feet of Gas burned per Hour.	Heating Results. Heat Units per Cubic Foot of Gas consumed. A. Units in Fresh-warmed Air passing through Stove Ducts.	B. Units developed from Outer Surface of Stove Casing.	C. Total Units utilized for Warming Purposes.	D. Approximation of Units passing away in Waste Products.	E. Total Units developed per Cubic Foot of Gas, being Sum of Cols. C and D preceding.	F. Units usefully used for Warming and Ventilation.	G. Percentage Figure of Comparison, Best Stove being taken as = 100.	Waste Products. A^1. Absolute Temperature of Combustion Gases leaving the Stove.	B^1. Increase of Temperature over the Normal.	C^1. Theoretical Cubic Feet of Air necessary to burn a Cubic Foot of the Gas, Calculated at 72° F.	D^1. Excess of Air supplied over previous Amount. Temperature 72° F.	Ventilation. Outlet Ventilation or Air extracted from Rooms by Stoves. A^2. Cubic Feet of Air at 72° F. taken out of Room by Stove per Cubic Foot of Gas burned.	B^2. Gross Cubic Feet of Air actually extracted by Stove per Minute. Calculated at 72° F.	C^2. Percentage Figure of Comparison. Best = 100.
Household coal	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—
Dr. Adams' stove	14.0	711.68	97.98	809.66	32.56	842.22	800.22	100.00	174°	130°	8.58	3.63	12.21	2.70	45.52
Dr. Bond's eu-thermic stove	12.0	58.66	495.75	554.41	34.23	588.64	546.64	68.00	122° 202°	67° 147°	8.58 8.58	18 33 24.92	26.91 33.50	5.26 6 70	80.30 100.00
Cox's ventilating stove	9.00	138.66	289.47	428.13	77.58	505.71	463.71	57.90	238°	194°	8.58	9.18	17.76	2.66	39.70
George's patent calorigen	8.26	118.90	295.41	414.31	189.53	603.84	414.31	51.50	290°	237°	8.58	34 57	none; from no ou	air for com-bustion not drawn from room, but outside, so tlet ventila-tion caused	
Wright's imperial stove	10.7	57.30	428.50	485.80	39.70	525.50	483 50	60.40	192°	129°	8.58	6.90	15.48	2.66	41.20
Waddell's stove	13.0	not tain	ascer-able	513.90	in-cluded in Col. C	513.90	151 60 (a)	18.90	not a tain	ascer-able	8.58	not ascer-tain-able	none	none	none
Gillingham's heat radiator	16.0	not tain	ascer-able	305.90	in-cluded in Col. C	305 90	none (a)	0.00	not a tain	ascer-able	8.58	"	none	none	0.00
Novel gas fire (Chas. Wilson)	15.0	—	—	—	—	513.60	471.60	58.90	—	—	8.58	—	—	—	—

NOTE.—In the two figures marked (a) in Col. F, a deduction is made of the

AT GLASGOW EXHIBITION, OCTOBER 1880.

Results.								Economic Results.				
Power of Stove warming Air from 32° to 72° F. per Cubic Foot of Gas burned.				Inlet Ventilation or Fresh-warmed Air passing through Stove Ducts into Rooms.				Units per cwt. of Coal per Cubic Foot of Gas and Relative Cost of each.				
A[3].	B[3].	C[3].	D[3].	A[4].	B[4].	C[4].	D[4].	A[5].	B[5].	C[5].	D[5].	
Gross Amount of Air warmed. Cubic Feet.	Proportion of Foregoing vitiated by Combustion Gases.	Cubic Feet of Air usefully warmed.	Percentage Figure of Comparison. Best = 100.	Increase over Normal Temperature for Outside Air.	Calculated Gross Bulk of Air the Stove can warm per Hour Units Col. A from 32° F. to 72° F.	Preceding Column divided by Gas burned = Relative Economy in warming Fresh Air.	Percentage Figure of Comparison. Best = 100.	Heat Units in Col. A as useful for Warming and Ventilation—deducting Allowance for Imperfect Combustion and Chimney Draught.	Cubic Feet of Gas required to equal preceding, less Amount required for Draught.	Comparative Cost of Fuel: Coal = 8d. per cwt. of 1,344,000 Units; Gas = 3s. 8d. per 1,000 Cub. Ft.	Figure of Comparison. Best Gas Stove = 1.	Remarks.
										s. d		
—	—	—	—	—	—	—	—	1,000,000	—	0 10½	0.00	This result is for heat developed in warming and ventilating. In ordinary open fires of improved type, the heat useful for warming purposes does not exceed from 15 to 35 per per cent. of the total in the coal, the balance (less deduction for imperfect combustion) passing away up the chimney, and so inducing ventilation from the room. Some close stoves are said to utilize 95 per cent. of heat for warming alone.
1138.5	none	1,138.5	100.0	159°	14,010.5 two ducts	1,000 75	100.0	1,000,000	1 249.60	4 6½	1.00	Temperature of products too low; also, if ducts are used to introduce air from outside, waste products are not drawn from room; otherwise a most excellent stove.
779.6	none	779.6	89.6	97°	989.7	82.48	8.3	1,000,000	1,836.05	6 8½	1.47	The double numbers, columns A[1] to D[1] and A[2] to C[2], are with throttle-valve, shut and open. Heating power taken with it shut. An excellent stove.
602.0	none	602.0	52.8	200°	1,754.8	194 98	19.4	1,000,000	2,156.52	7 10½	1.73	Stove heated by white-flame burner; neat and well finished.
582.6	none	582.6	51.2	219°	1,381.0	167.19	16.7	1 000,000	2,413.65	8 10	1.93	Column C correct, but D probably over the actual. Air for combustion must come from outside—so units in D lost for ventilation, thus accounting for cost of fuel in C[5], notwithstanding number in C. Flue arrangements useful in exposed situations.
683.1	none	683.1	60.0	56°	864.8	80.57	8.0	1,000,000	2 280.50	8 4½	1 83	Similar to euthermic stove, but without throttle-valve, the want of which, together with inferior lighting arrangement, might, without careful attention, induce explosion; also temperature of waste products too low; otherwise a good stove.
722.64	502.63	220.0	18.4	—	none	none	0.0	1,000,000	6.596.30 2,118.80	24 2 7 9	5 29 1.69	This stove has no flue to carry off combustion gases, so cannot provide ventilation, and vitiates a great proportion of the air it can warm 40° F. The lower figures in columns B[5], C[5], and D[5] show the relative cost of fuel had a flue been provided, taking proportion per E.
450.1	502.63	more air is vitiated than is warmed	0.0	—	none	none	0 0	1,000,000	—	results in loss to consumer	infinite	A flueless and so-called condensing stove, heated by single argand burner. Makers state that flues can be supplied, but no apparent provision made for such in apparatus tested. Vitiates more air than it can warm 40° F., but sample tested did not appear suited for Scotch gas.
—	—	—	—	—	—	—	—	—	—	—	—	This fire, intended to be placed in an ordinary grate, was placed bodily in test-casing or room, and so tested only for total heat developed, both for warming and ventilating, the relative proportion being probably similar to that of an ordinary open fire.

units necessary to carry off the air rendered impure by the combustion gases.

estimate the comparative *cost* of these various appliances merely in terms of the fuel used by them would not convey an accurate notion of their relative

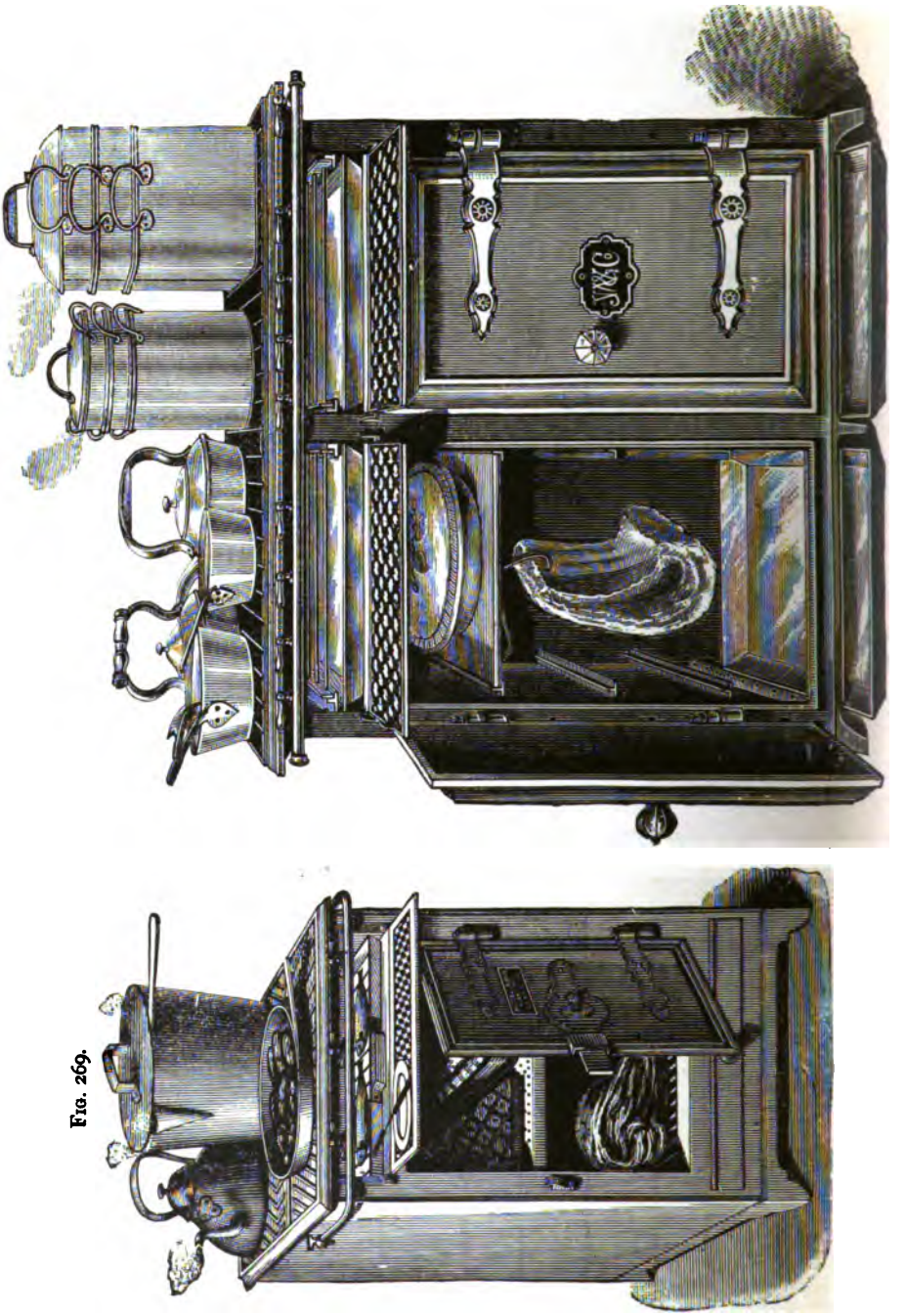


Fig. 269.

value. Estimates have been made by Mr. J. R. Napier, in the paper re-

ferred to *supra ;* by Dr. Wallace ;* by Mr. T. Fletcher, of Warrington, in his paper on "Economy of Fuel in Domestic Operations;" and by Mr. T. Box, in his "Practical Treatise on Heat;" but, in the main, these estimates do not take into account the useful effect obtained in practice (and not merely in experiment), the proportion of waste in each case, or the elements of cost, in the shape of labour, and trouble which accompany the use of coal and are absent from that of gas. In domestic affairs, the lessened labour and trouble, in spite of a more expensive fuel, will often turn the scale in favour of heating by gas; but, for heavy and continuous heating work, it is certain that ordinary illuminating gas cannot, from its cost, compete with coal.

FIG. 271.

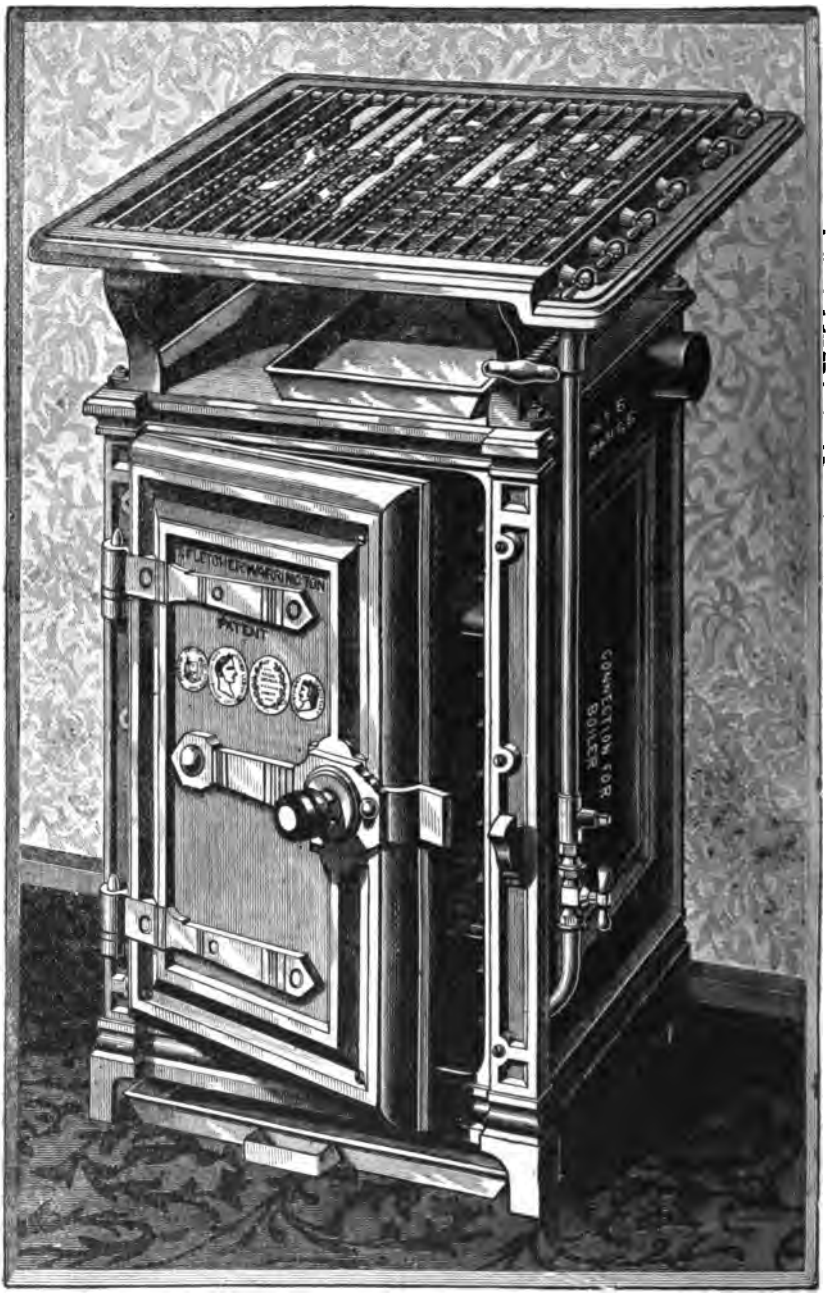
Where, however, producer gas or water gas can be applied and used, the case is very different, and it is probable that even domestic heating by gas of this quality will be found to be more economical than where coal is burned in stoves, the economy of heating in manufacturing operations by means of producer gas having been fully proved.

Gas Cooking-stoves.—These are arranged in various ways as to the burners used, and the application of the heat to the food cooked in them. Some, like those of Wright, Fletcher, and others, make use entirely of Bunsen or non-luminous flame burners. Others, such as Waddell & Main's cookers, have naked luminous jets; or, like Verity Bros.', have incandescent brick

* On the Heating Power of Coal Gas, "Proc. Phil. Soc. Glasgow," vol. xii. p. 208.

burners in the main portion of the stove; and others, of which Dr. Adams' cooking-stoves are so far the only examples, have incandescent burners placed

FIG. 272.

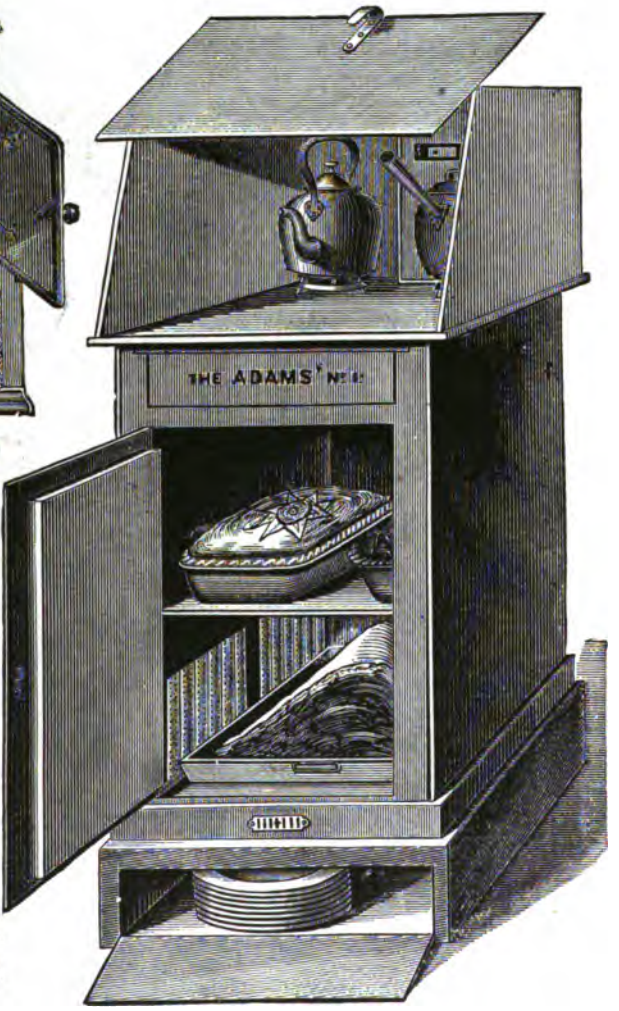


behind talc screens, so that only the radiant-heat rays are used, the hot gases being conducted away out of contact with the food.

The operations of boiling are best carried out by means of Bunsen ring or similar burners, as the quality of flame produced by them is suitable for contact with metal vessels in which food has to be boiled. If non-luminous flames are used in the body of the cooking-stove, however, where roasting operations are to be conducted, the meat is cooked by contact with the hot gases, and the conditions of an oven are approximated, the difference being that in a close oven the meat is preserved from contact with any-

Fig. 273.

Fig. 274.



thing but hot air, and the vapours given off from the meat itself; whilst in gas cooking-stoves of this kind it is in contact with the gases given off from the always somewhat imperfect combustion of the gas fuel, besides other vapours. Luminous jets and incandescent burners supply radiant-heat rays, which are required in the operation of roasting; and of the two kinds of stoves having radiating burners, the one which preserves the meat from contact with the hot products of combustion while it is being roasted, is preferable from a theoretical point of view.

In general appearance, most of the gas cooking-stoves resemble each other—they consist of an iron casing, with one or more doors giving access to the body of the stove; a perforated top, having ring or other burners at

various points; and often between the body of the stove or "oven," and the top, there is a narrow space in which trays can be placed. The oven is divided by shelves, and burners or gas jets are placed round the sides near the bottom. These jets are luminous in the stoves of R. & A. Main, Fig. 269,

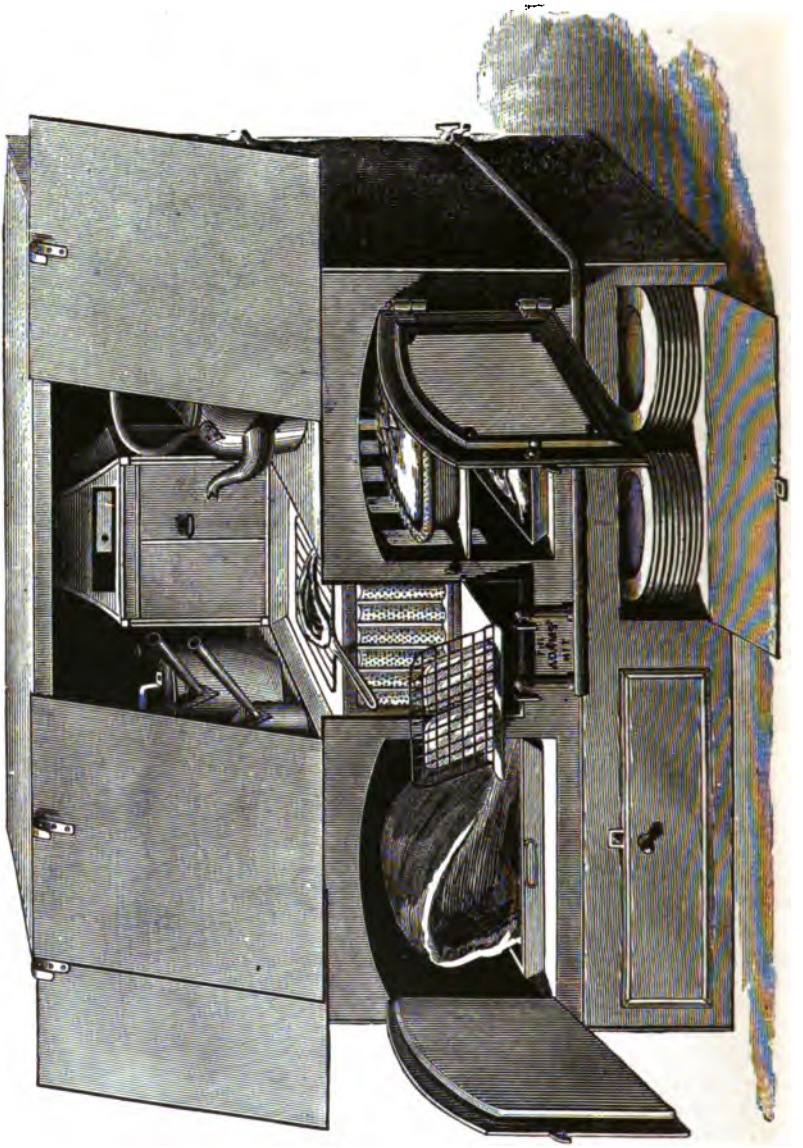


Fig. 275.

non-illuminating in the majority of other designs, such as Wright's, Fig. 270, or Fletcher's, Figs. 271, 272.

In some cases, as in Wright's reflector cooker, Fig. 273, luminous jets are used in combination with reflectors so as to concentrate the radiant-heat rays upon the meat being roasted; whilst in Fletcher's, Verity's, and the

Retort Gas Stove Company's stoves, special burners are used for the purpose of developing a greater degree of heat from the combustion of the gas.

All gas cooking-stoves should be lined with fire-brick or other non-conducting material, and should have provision for carrying off the gases and vapours to a chimney or ventilating shaft. This should include the top of the stove as well as the body, but, except in the case of Dr. Adams' cooking-stove, this does not seem to have been attended to.

The Adams cooking-stove, illustrated in Figs. 274, 275, is the only one introduced, as yet, in which, along with the use of incandescent burners, the hot products of combustion are kept from contact with the food being cooked, and are used for oven-heating, boiling, &c., as in close cooking ranges constructed for coal firing. There is certainly novelty and merit in this system of construction as applied to gas cooking-stoves.

In testing the efficiency of gas cooking-stoves, it is usual to ascertain the maximum temperature reached and maintained by means of a recorded consumption of gas. The practical test of cooking some meat of various kinds is also resorted to; but there are no records of tests in which the effects due to convection and to radiation are discriminated. The following table and that on p. 432 give the results of the tests carried out at Glasgow, and at the Exhibition in London in 1882–83. No doubt, the chemical effects on food which are included in the term "cooking" are, in the main, due to elevation of temperature; but there is also a difference in the result produced by different qualities of heat, as may be witnessed to by the difference between a baked and a roasted joint.

Extracts from Practical Cooking Tests, and Tests for Heating up and Loss by Radiation, made by Examiners at Gas Exhibition, Glasgow, October 1880.

Maker and Name of Stove.	Condition of Food cooked.	Total Time taken.	Total Gas used in cooking.	Gas burned per lb. of Food put in Stove.	Degrees Fahr. Increase in Oven per Minute.	Gas burned in Oven per Minute.	Gas burned per Degree Increase of Temperature.	Percentage of Gas lost Heating up and by Radiation in Two Hours.
		h. m.	cub. ft.					
Main's "universal domestic"	Meat well done	1 25½	22.60	1.88	27.00	0.270	0.0 0	15 7
	Bread "							
Wilson, of Leeds, "eclipse" gas kitchener . .	Well done .	2 17	30.00	1.25	20.50	0.260	0.013	19 4
Wright's "gas cooker," No. 492 . . .	Excellent .	1 30½	12.00	1.00	11.66	0.120	0 010	32 0
Cox's "save all" . .	" .	2 49	23.80	1.48	8.88	0.139	0 015	22.6
" "dispatch" . .	" .	2 20	17.50	1.45	20.40		0.009	14.0
Beverley & Wilde's "Leeds family kitchener"	Meat well done .	1 55	29.06	2.42	20.70		0.015	14.0
	Bread "							
Billing & Co.'s "sun-dial"	" " .	2 6½	21.71	1.81				
Fletcher	Meat underdone	1 53	19.50	2.43				
	Bread well done							

In connection with both heating and cooking stoves using gas fuel, there is a matter of some interest which offers a field for investigation—viz., the proportions employed in the various so-called "Bunsen" mixers or induction jets, for producing the mixture of gas and air used in Bunsen or non-luminous flames. There exists no information as to the influence exerted by the shape and dimensions of the gas nozzle and of the delivery tube for the

TESTS OF GAS COOKING-STOVES MADE BY MR. D. K. CLARK, C.E., AT THE INTERNATIONAL ELECTRIC AND GAS EXHIBITION, LONDON, 1882-83.

	Exhibitor.	Designation of Stove.	Capacity of Oven. cub. ft.	Jet Area. sq. ins.	Inlet Area. sq. ins.	Weight of Joint. lbs. oz.	Percentage of Joint cooked.	Gas consumed in Roasting. cub. ft.	Gas per Hour. cub. ft.	Gas per Pound of Joint. cub. ft.	Time Roasting. h. m.	Time per Pound. mins.	Average Temperature in Oven. Fahr.
1	John Wright & Co.	Eureka Artisan, No. 496	1.15	0.44	20.50	7 0⅜	74.2	13.9	6.68	1.97	2 5	17.8	345°
2	H. & C. Davis & Co.	Metropolitan, No. 8	1.67	0.37	25.00	7 8	81.9	13.9	6.95	1.85	2 2	16.3	425
3	West Bros.	No. 201A	1.80	0.62	35.25	8 13½	74.9	21.0	9.68	2.38	2 10	14.8	400
4	General Gas Lighting and Heating Apparatus Co.	Nonpareil, No. 55 (new)	2.33	0.66	37.50	7 10	74.6	18.8	6.84	2.47	1 57	15.3	350
5	Waddell & Main	Universal Domestic, No. 3 (plain gas)	2.36	—	12.25	9 1⅛	67.7	21.3	9.19	2.34	2 19	15.3	381
6	Ditto	Ditto (atmospheric gas)	2.36	0.55	12.25	8 5⅛	70.7	19.5	9.15	2.34	2 8	15.3	355
7	John Wright & Co.	Eureka, No. 410	2.40	0.66	13.50	7 14⅛	75.9	21.5	10.75	2.77	2 0	16.2	380
8	Ditto	Ditto	2.40	0.66	13.50	11 6	75.9	29.2	10.62	2.56	2 45	16.5	
9	H. & C. Davis & Co.	Metropolitan, No. 9	2.68	0.61	38.60	13 0	77.0	29.2	9.11	2.25	3 9	14.5	348
10	Ditto	Ditto (new)	2.68	0.61	38 60	8 4	77.3	20.9	8.71	2.53	2 25	17.6	373
11	General Gas Lighting,&c.,Co.	Nonpareil, No. 56	2.73	0.39	68.00	8 6½	81.0	22.2	9.87	2.64	2 15	16.1	359
12	Chas. Wilson & Sons	Eclipse	3.05	0.56	16.70	7 13	71.6	26.2	13.10	3.36	2 0	15.4	374
13	E. Liddaway & Sons	Paragon, No. 624	3.29	0.45	41.00	8 4	76.3	21.9	10.19	2.65	2 9	15.6	389
14	Deane & Co.	Fletcher's Range, No. 3	3.33	0.64	62.00	8 8⅛	75.1	25.8	10.90	3.03	2 22	16.7	399
15	General Gas Lighting,&c.,Co.	Nonpareil, No. 56 (new)	3.36	0.39	24.00	7 14	77.8	19.0	9.50	2.40	2 0	15.2	360
16	Ditto	Ditto, No. 16	3.47	0.42	46.50	8 0	71.8	24.5	12.30	3.06	2 0	15.0	356
17	Ditto	Ditto (backward jets only)	3 47	0.17	46.50	9 8	72.6	29.5	12.45	3.11	2 22	15.0	350
18	Ditto	Ditto (forward jets only)	3.47	0.12	46.50	9 2	65.8	22.3	10.00	2.47	2 15	15.0	366
19	H. & C. Davis & Co.	Metropolitan, No. 10	3.55	0.37	46.00	9 0	70.9	22.7	9.90	2.52	2 17	15.2	362
20	General Gas Lighting,&c.,Co.	Nonpareil, No. 16 (new)	3.60	0.51	46.00	8 2	76 3	26.3	13.20	3.24	2 0	14.8	400
21	Ditto	Ditto (forward jets only)	3.60	0.12	46.00	8 5	82.0	22.6	9.42	2 72	2 23	17.2	361
22	Ditto	Ditto (backward jets only)	3.60	0.39	46.00	8 14	73.0	24.3	11.25	2.73	2 15	15.2	376
23	William Stobbs	Beverley & Wylde's, Sydney	3.84	1.10	60.00	8 5	77.4	30.5	15.25	3.67	2 0	14.4	459
24	General Gas Lighting,&c.,Co.	Nonpareil, No. 57 (new)	5.10	0.34	13.70	9 12	82.4	27.7	11.10	2.84	2 31	15.4	338

mixture of gas and air, and the effect on the composition of the mixture produced by different ratios of area of gas to that of air inlet used at varying pressures of gas. The practice in the construction of Bunsen mixers, which are exhibited in Figs. 276–279, shows that there is no rule or formula to guide

Fig. 276.

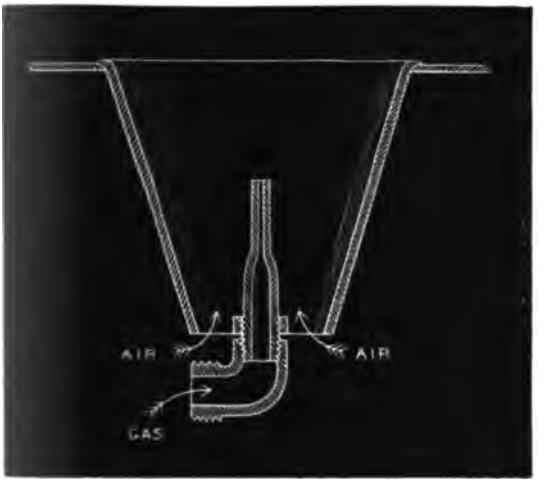


Fig. 277.

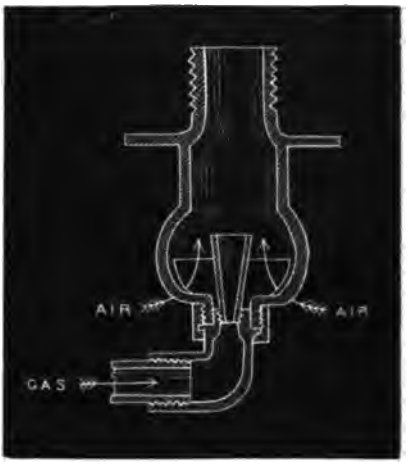


Fig. 278.

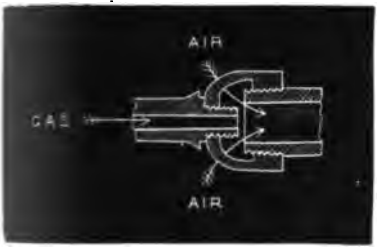
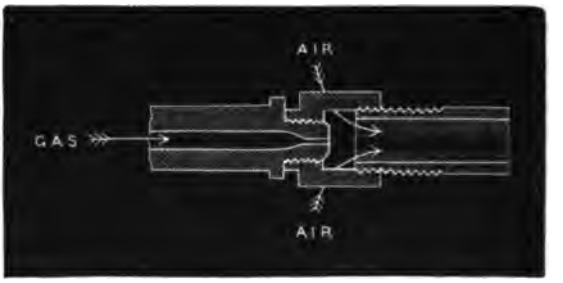


Fig. 279.



in fixing proportions under the ordinary variations of pressure in towns. The sizes of some were investigated by Mr. W. Denny, who has given the following results:*—

Mixer employed in	Area of Gas Nozzle. A. Square Inches.	Area of Minimum Air Space. B. Square Inches.	Ratio of B. to A.
Gas fires—			
Hislop's (Fig. 276) . . .	.0164	1.230	75.00
Verity's (Fig. 277) . . .	.0338	0.368	10.89
Heating-stoves—			
Adams'	.0014	0.053	27.86
Wright's imperial (Fig. 278) .	.0167	0.109	6.53
Cooking-stove—			
Main's (Fig. 279) . . .	.0044	0.242	55.00

Exit Gases and Soot.—A number of open stoves were tested at the Kensington Smoke Abatement Exhibition (1881), and a valuable chemical report on the results was drawn up by Professor W. C. Roberts, F.R.S.

* "On Cooking and Heating by Gas."

Péclet's early experiments (1828) had dealt with too small fractions of flue gases to be more than indicative. Forty years later (*Bull. Soc. Ind. Mulhouse* [*Mémoires*]; Paris: Lacroix, 1875) Scheurer-Kestner and Meunier showed that, in boiler furnaces, even with a 50 per cent. excess of air, the products of combustion always contained imperfectly burned compounds, only 80 per cent. of the hydrogen being, in fact, consumed. They also observed that, when the layer of incandescent fuel is thin, the unburnt carbon in the gas is more apt to be present as hydrocarbons than as carbonic oxide.

Roberts draws attention to Cailletet's discovery that, if the gaseous products of combustion be collected very near the fuel, they will contain more carbonic oxide than when cold—that gas, in fact, combining with oxygen during the act of cooling. The flue gases in the South Kensington experiments were in each case collected at a distance of 10 feet from the burning fuel; and the thermometer and anemometer were inserted close to the point of collection.

The chemical arrangements included: (1) an asbestos filtering tube, 84 per cent. of the increase in weight of which represented *soot*; (2) a drying apparatus containing calcic chloride; (3) soda-lime tubes to collect carbonic acid; (4) a combustion apparatus, to burn completely any now remaining hydrocarbons and carbonic oxide; (5) a drying tube; (6) soda-lime tubes.

The results of eighty-five cases examined show that the weight of completely burned carbon is to that present in the form of carbonic oxide or hydrocarbons as 1,000 : 4 to 1,000 : 375. There were, however, only nine cases in which a ratio of 1,000 : 200 was exceeded, and but three in which the ratio was less than 1,000 : 10.

According to Scheurer-Kestner's experiments (*loc. cit.*), the amount of carbon in soot seldom exceeds 1 per cent. of that in the fuel burned. Soot, especially that which is deposited near to a furnace, is always rich in heavy tarry hydrocarbons in addition to actual carbon; and it invariably, in such positions, contains more light ash, carried forward by the draught.

The tables given at pp. 435–438 contain a record of the experimental results.

Heating by Means of Channels or Flues.—The method of applying heat by means of flues, which is one of the most ancient, having been used by the Romans for heating their baths, is still often practised in hot-houses. The hot gases and smoke produced in a grate placed at a lower level and on the outside of the space to be heated are conducted through a system of flues under the floor, where they part with their heat and then escape by the chimney. Unfortunately, this mode of applying heat, certainly the best adapted for dwellings, can only be managed in the lowest floor of the house, and even there with difficulty. Great care must be taken to surround the lower part of the flue with rubbish or some non-conducting substance, so as to prevent any loss of heat in that direction. The position of the fire with reference to the area to be heated forms the only essential difference between this method of heating and that with the close stove.

Heating by Means of Hot Air.—When greater security, want of space, or other considerations render it desirable to remove the stove to a distance from the apartments to be heated, the necessary quantity of air can be warmed in another part of the building, and conducted by air-flues into the different rooms.

Heating by hot air is the designation exclusively given to this method, although it applies with equal propriety to many of the others, the air being in nearly every case the medium through which the heat ultimately reaches its destination. When the supply of warmed air is abundant, and is trans-

RESULTS OF CHEMICAL TESTS OF GRATES AND STOVES.

CLASS I.—*Open Grates, having Ordinary Bottom Grids and Upward Draught.*

No. of Test.	No. of Testing-room.	Name of Exhibitor.	Description.*	Nature of Fuel.	To every 1,000 Parts of Carbon as CO_2 there are of Carbon as C_xH_y + CO	To every 1,000 Parts of Carbon as CO_2 there are of Hydrogen free and combined with Carbon in the gaseous State	Weight of Matter retained by Asbestos in Grains.	Coal burnt per Hour.	Total Average Smoke Shade (Mr. Clark).
1	2	3	4	5	6	7	8	9	10
								lbs. ozs.	
1	1	J. G. Gray	Open grate, perforated loose back	Wallsend	76	84	0.045	3 1½	2.80
2	4	Barnard, Bishop, & Barnards	The anthracite grate	A mixture of Wallsend and anthracite	95	83	0.045	2 1½	1.92
3	4	The British Sanitary Co.	Basket grate, inclosed in sheet-iron and glass, heating air	Wallsend	143	51	0.045	3 0	4.70
5	2	M. Perret	Radiating fire-grate, fire-brick lining and roof	Coke	45	77	0.030	6 3½	0.00
6	5	J. Wright & Co.	Hygienic ventilating stove	Wallsend	49	65	0.070	6 5½	3.90
7	2	M. Perret	As before	Anthracite	69	48	0.070	4 1½	0.60
8	2	,,	,,	Wallsend	234	111	0.200	7 2	0.80
10	3	T. Potter & Sons	Open grate (hot-water pipes), air-heating	,,	239	—	0.215	3 12	3.50
11	3	Perceval & Westmacott	Parlour stove, for heating and for cooking, air heated	,,	73	—	0.915	2 6½	2.60
15	4	T. Nash	Open grate, back down-draught to deposit soot	,,	163	219	0.090	3 9	4.80
17	2	W. P. Taylor	Fresh-air opening in hearth, fluted and perforated back	,,	43	259	0.065	3 14½	2.60
18	2	The Radiator Range Co.	Combustion chamber at back of grate	,,	76	30	0.040	3 10½	—
19	5	A. B. Verrier	"Comet grate," fire-brick lining, blower, heating fresh air, and drawing foul air from upper part of room	,,	168	29	0.060	3 13½	3.70
20	5	,,	Do. do.	,,	138	77	0.080	4 6	2.70
21	2	Rosser & Russell	Fire-clay back, fluted, air heated	,,	39	52	0.110	3 6½	1.90
23	5	G. Haller & Co.	Kohlhofer's hot-air stove, air-chamber above and at sides, up and down pipe flues	,,	84	—	0.030	6 2½	3.00
24	4	Perceval & Westmacott	Sanitary stove	,,	54	17	—	3 9½	5.50
25	3	The Radiator Range Co.	As before	,,	101	26	0.050	4 15½	—
26	4	E. H. Shorland	The Manchester grate, G. L. Shorland's patent. Air heated and carried off in pipes	,,	23	—	—	6 9	2.90
29	1	J. Wavish, plain grate	Plain grates	,,	164	52	0.195	3 11	2.50
30	1	Do. with apparatus	Air-cylinder in heart of fire	,,	78	97	0.085	—	1.30

* See note to table, p. 438.

RESULTS OF CHEMICAL TESTS OF GRATES AND STOVES—(*continued*).

CLASS II.—*Open Grates, having Solid Floors, adapted for Slow Combustion and Upward Draught.*

No. of Test.	No. of Testing-room.	Name of Exhibitor.	Description.	Nature of Fuel.	To every 1,000 Parts of Carbon as CO_2 there are of Carbon as $C_xH_y + CO$	To every 1,000 Parts of Carbon as CO_2 there are of Hydrogen free and combined with Carbon in the Gaseous State	Weight of Matter retained by Asbestos in Grains.	Coal burnt per Hour.	Total Average Smoke Shade (Mr. Clark).
1	2	3	4	5	6	7	8	9	10
								lbs. ozs.	
33	2	Barnard, Bishop, & Barnards	Glow fire, brick slabs	Wallsend	90	79	0.085	2 2½	3.8
34	3	" " "	Bartlet grate, brick slabs	" and coke	111	64	0.105	2 15	3.0
35	2	" " "	" "	" and anthracite	205	108	0.050	3 5½	5.1
36	4	The Derwent Foundry Co.	Abbotsford grate, "	"	275	95	0.135	2 8½	4.2
38	2	Doulton & Co.	Fire-place of fire-brick slabs	"	48	70	0.040	3 15½	1.3
39	4	J. B. Petter	Nautilus grate	"	83	66	0.070	2 4	3.9
41	5	F. Edwards & Son	Dr. Arnott's grate	"	233	68	0.150	3 9	3.1
42	5	" "	Downward burning grate	"	175	46	0.175	3 13½	2.3
45	2	Frost & Winfield	Fire lumps and baffle roofs	"	77	58	0.045	3 8½	4.4
46	3	Barnard, Bishop, & Barnards	Glow fire	"	195	81	0.105	2 1	2.4
CLASS III.—*Open Grates, Under-fed; supplied with Fresh Fuel beneath the Incandescent Fuel, with Upward Draught.*									
53	4	F. R. Hollands	Under-feeding, with movable grate	Wallsend and cinders	103	67	0.015	2 9½	2.5
55	3	Brown & Green	" with tray in front	"	32	41	0.020	4 0½	2.1
56	4	W. S. Melville	" shovel	"	96	69	0.095	2 4½	4.2
57	5	E. H. Shorland	"Princess Louise" (G. L. Shorland's patent), under-feeding by shovel	"	114	41	0.055	2 7	3.0
58	3	Yates, Haywood, & Co.	Under-feeding, with movable grate	"	145	16	0.080	3 4	2.3
CLASS IV.—*Open Grates, to which Fresh Fuel is supplied from the Back, or the Sides, or Hoppers.*									
60	4	A. C. Engert	Coking box at back	Wallsend	164	67	0.105	2 13½	.9
		HOPPER-FED.							
61	4	Musgrave & Co.	"Ulster" register stove, hopper at back, heats air	" and cinders	187	103	0.050	5	2.2
62	3	The Coalbrookdale Co.	Gassius grate, hopper-fed, solid bottom	"	98	103	0.035	3 8	1.8
63	4	J. M Stanley	Downward draught, hopper-fed	"	19	16	0.075	5 6½	2.2
65	4	H. E. Hoole	Hopper at each side, openings at bottom reflect on front	"	78	79	0.065	2 8½	2.5
67	4	Archibald Smith & Stevens	"Wonderful grate," hopper at back	"	96	39	0.075	5 0½	4.3

CLASS V.—*Open Grates, having a Downward, a Backward, or a Lateral Draught.*

No. of Test.	No. of Testing-room.	Name of Exhibitor.	Description.	Nature of Fuel.	To every 1,000 Parts of Carbon as CO_2 there are of Carbon as C_xH_y + CO	To every 1,000 Parts of Carbon as CO_2 there are of Hydrogen free and combined with Carbon in the Gaseous State	Weight of Matter retained by Asbestos in Grains.	Coal burnt per Hour.	Total Average Smoke Shade (Mr. Clark).
1	2	3	4	5	6	7	8	9	10
								lbs. ozs	
68	4	The Coalbrookdale Co.	Kyrle grate, fire-brick lining and floor, backward draught at bottom	Anthracite	42	28	0.005	1 11½	0.0
70	3	Captain T. E. Clarke	Downward draught, air heated behind	Wallsend	77	141	0.040	2 9	1.8
71	4	The Derwent Foundry Co.	Smoke-burning register (Jobson's patent), downward and backward draught, tubular air-bars	,,	49	53	0.035	5 4	3.2
72	3	M. Feetham & Co.	Ventilating dog grate, fire-basket, downward draught	,,	213	34	0.045	4 13½	1.2
73	3	,, ,,	Hurst grate, downward and backward draught, air heated	,,	243	—	0.035	3 4	1.4
74	3	,, ,,	Do. do.	Anthracite	113	166	trace	2 3	1.3
76	4	Yates, Haywood, & Co.	Redmayne's patent, backward draught, solid floor, air heated	Wallsend	119	48	0.135	4 8½	4.7
77	4	,, ,,	Do. do.	Anthracite	49	59	0 000	3 11	0.3
79	3	Deane & Co.	Crane's anthracite grate, fire-brick back and sides, downward draught	Wallsend	83	—	0.020	3 0½	3.9
80	4	J. Moore	Draught backwards and downwards, air heating	,,	38	66	0.060	3 4	2.5
81	2	Steel & Garland	"Kensington" back and side draughts into flue, air heating	,,	125	13	0.090	3 9½	3.7
82	4	Clark, Bunnett, & Co.	Ingram grate, backward draught, air heating	,,	31	35	0.110	5 11½	3.3
83	4	,, ,,	Do. do.	Anthracite	16	41	0.005	4 15½	0.0
84	2	Steel & Garland	"Kensington," as above	,,	177	219	0.010	6 3½	0.0
85	3	Brown & Green	"Luton" register grate, backward draught	,,	78	43	0.005	2 9½	0.0
86	3	J. T. Reeve	Reeve & Henry's smoke purifier, hob grate, backward draught, and filter chamber	Wallsend	128	174	0 045	1 6½	1.6
88	2	T. E. Parker	Downward and backward draught	,,	7	8	0.050	3 7	2 2
89	3	,,	The same grate, but less air admitted	,,	44	60	0.035	3 2	2.4
90	3	J. Cornforth	Hollow air-bars and backward draught	,,	95	59	0.130	4 13½	3.5
—	2	Deard	Down draught water heating apparatus	,,	87	23	0.015		
—	4	T. E. Parker	Down draught hot air	,,	—	34	0.000		-

RESULTS OF CHEMICAL TESTS OF GRATES AND STOVES—(*continued.*)

CLASS VI.—*Close Stoves.*

No. of Test.	No. of Testing-room.	Name of Exhibitor.	Description.	Nature of Fuel.	To every 1,000 Parts of Carbon as CO_2 there are of Carbon as C_xH_y + CO	To every 1,000 Parts of Carbon as CO_2 there are of Hydrogen free and combined with Carbon in the Gaseous State	Weight of Matter retained by Asbestos in Grains.	Coal burnt per Hour.	Total Average Smoke Shade (Mr. Clark).
1	2	3	4	5	6	7	8	9	10
								lbs. ozs.	
96	3	Musgrave & Co.	Slow combustion stove	Coke	61	37	0.000	2 3½	0.0
97	2	Rev. H. J. Newcombe	Tubular air warmer	Wallsend	49	20	0.060	3 7	2.0
99	3	C. Portway & Son	Tortoise stove, slow combustion heating and laundry stove	Coke	77	41	0.010	2 0½	0.0
101	2	Doulton & Co.	Spiral stove of stoneware, air heating	Hard steam	224	86	0.070	1 1	1.0
102	4	H. Hunt	"Economy" portable heating stove	Anthracite	375	58	—	2 8	0.3
104	4	Yates, Haywood, & Co.	"Miser" stove, two pillars	Wallsend	110	39	0.175	1 13½	4.5
105	2	J. Cornforth	"Little Wonder" stove	"	7	39	0.035	3 12	0.7
106	5	R. W. Crosthwaite	Armstead's stove No. 3, delivering hot air to burn the gases	Anthracite	22	36	0.020	4 14½	0.5
111	5	W. Stobbs	Crystal ventilating grate	"	96	83	0.005	2 0½	0.8
113	5	H. Hunt	"Crown Jewel" base burner hall stove	"	114	66	0.005	2 6½	0.0
115	4	Van der Harst	Charcoal stove	Compressed charcoal	180	33	—	0 11	0.0
117	3	Brown & Green	"Twin" stove	Hucknall bituminous coal	90	94	0.030	3 12½	3.1
118	3	J. F. Farwig & Co.	"Calorigen" stove, air heating	Wallsend	114	34	0.080	2 12½	1.2
120	5	J. Dunnachie	"Star" heating stoves, fire-brick	"	34	94	0.030	5 0½	2.5
122	5	W. Barton	"Premier" stove	Coke	26	—	0.025	3 10½	0.0
123	5	F. Lönholdt	Anthracite stove, air heating *	Anthracite	132	109	trace	1 4½	1.5
125	5	"	" †	"	19	43	trace	3 12½	0.0
126	5	H. J. Piron	Hot-air stove and ventilator	"	35	53	0.005	6 10	0.0
127	5	R. W. Crosthwaite	Armstead-Gregory stove	Wallsend	16	30	0.050	7 2½	0.5
129	3	Brown & Green	Close stove, with reversible draught	Hucknall	71	52	0.070	4 15½	2.4
—	5	Churchill	Cold air	Wallsend	254	119	0.050		
—	2	Deard	(Water coil)	Anthracite	99	74	0.005		

* Slow combustion. † Rapid combustion.

NOTE.—The numbers and descriptions correspond with those given by Mr. Clark.
Under-feeding consists in placing cold fuel under that which is already ignited.
A *coking box* is a closed receptacle in which the fuel is gradually heated, the volatile products of the distillation being usually made to pass through the fire.
A *downward draught* causes the products of combustion and air to pass downward through the incandescent fuel, before entering the flue at or below the level of the grate.
A *backward draught* passes horizontally through the fuel, and enters the flue at a point either level with or below the surface of the fire, while a *lateral draught* enters the flue at the side.
Air heating implies that fresh air is heated by the appliance before entering the room. In some cases, such as Nos. 88, 89, 90, 105, and 106, attempts are made to effect the consumption of smoke by heating air before it mixes with the products of combustion in the flue.
In the so-called *base burner* the draught is brought directly down from the fire-place of a close stove, and circulates round the base.
In *slow combustion*, ignition of the fuel is maintained by the admission of as little air as possible.

mitted to the apartments with a certain amount of force by machinery, no extra outlet for the vitiated air is necessary, sufficient ventilation being afforded, in small rooms which are not overcrowded with inmates, by the unavoidable crevices in windows and doors. Special means of ventilation must be provided for crowded apartments. With a view to economize the heat of the air which has already circulated once through the apartments, two methods have been proposed. The one consists in reconducting the air to the heating surface of the stove, and again transmitting it to the spaces to be warmed; this practice is decidedly objectionable, as the air which has once passed through the lungs is no longer fit to support respiration. It is far better to conduct it to the ash-pit of the stove to supply oxygen to the fuel, where the higher temperature, as compared with the external atmosphere, which it still retains, will more than compensate for the lesser proportion of oxygen which is present. If 1 lb. of air-dried wood requires 5 lbs. = 123 cubic feet of air at 0° C. for combustion. and if, according to Rumford, 26 lbs. of water can be heated by it to 100° C., or $4 \times 26 = 104$ lbs. of air to 100° C., or $\frac{100 \times 104}{20} = 520$ lbs. of air to 20° C.; then the temperature of 20° (instead of 0°), at which, in this instance, the air is furnished to the fire, will correspond with a consumption of $\frac{1 \times 5}{520}$ = nearly 0.01 lb. of wood, which must consequently be saved.

This saving of 1 per cent., or something more, when the temperature exceeds 20° C. (68° F.), is too small to warrant any particular attention, and it is found judicious in practice to combine the two methods. The air, which has circulated for some time, may be allowed access to the hearth, and is replaced by air from without, the heating of which will then cost just as much as has been saved by employing the other for feeding the fire. Supposing that proper ventilation can be kept up in a room by means of doors and windows, the first method will necessarily be highly advantageous; the warm air streaming in will force out that already in the room, and thus produce a state of things in which the tendency of the external air to force its way through the crevices will cease with all its attendant disadvantages. It is quite certain that the loss occasioned by supplying the fire with cold air is counterbalanced by the advantage gained. The method of heating by hot air is not desirable for buildings in which the number of rooms heated varies from day to day, because the proper relation between the dimensions of the stove and the supply of hot air cannot be easily accommodated to meet a fluctuating demand. In other respects, this method of heating is economical; one stove only is required, and the fuel is more completely consumed than if the same quantity were distributed in separate stoves; lastly, the advantage of a uniform, equable heat, proceeding from the level of the floor, fully compensates for any loss occasioned by the transit of the hot air through the flues.

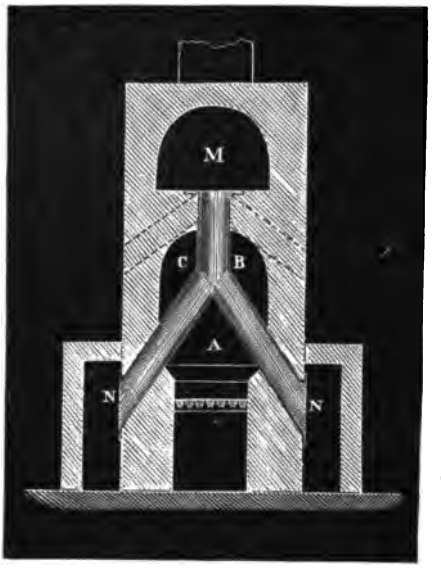
Hot-air Stoves.—Two systems are adopted in constructing these hot-air stoves. In the one the smoke and hot gases are caused to circulate in an extensive series of metallic or stoneware flues, and the air to be warmed, supplied from the outside of the building, is conducted to the outside of these, where it absorbs heat from their surfaces and from the inner side of the case of the stove. In the other, the air to be warmed is conducted through metallic or stone-ware pipes, round which the flame and smoke are allowed to play; the internal surface of the air-tubes is in this case the only source of heat. About 10 square feet of heating surface per lb. of coal consumed is found practically to work well in both systems.

The forms of apparatus constructed by different inventors for heating

the air are numerous. The following illustrations will give a general idea of this method of heating dwellings.

Fig. 280 represents a lateral section of a series of cast-iron pipes, in the form of an inverted Y, set in brickwork, parallel with each other, over a furnace. The flame from the furnace, after travelling to the end of the angular vault of pipes through the flue *A*, returns through *B*, and passes back again to the chimney through *C*. Air from the exterior is supplied to the pipes through the flues *N N*, and the heated air collects in the chamber *M*. Other pipes may be inserted with iron cement, in the position indicated by the dotted lines, when they will form a portion of the upper flues *B* and *C*. The position of the pipes in this arrangement is such that the joints are well protected by a body of masonry, and there is little danger of smoke from the fire mixing with the current of warm air. The lower side of the pipes, immediately above the fire, is apt to be too much heated, but this can be prevented by carrying a brick arch along the hottest part of the flue, between the flame and the pipes. The effect of the apparatus is very much increased by employing pipes that are cast with longitudinal internal and external projections, when a larger surface of metal is exposed both to the fire and the air-current.

Fig. 280.



Figs. 281, 282, 283, and 284 represent the hot-air stove of M. René Duvoir, much used in large workshops and manufactories in France. Fig.

Fig. 281.

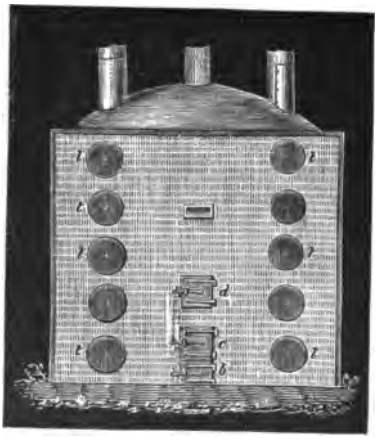
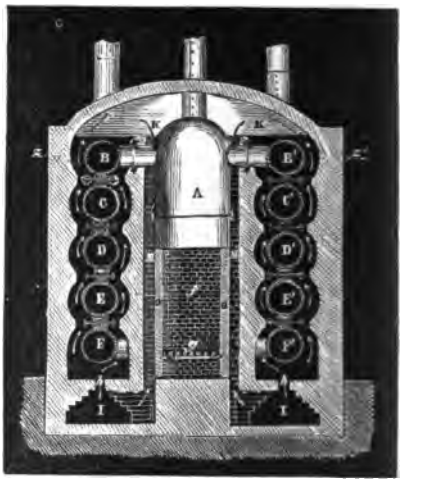


Fig. 282.



281 is an elevation; Fig. 282, a section on the line $x x'$ (Fig. 284); Fig. 283, a section on the line $y y'$ (Fig. 284); and Fig. 284, a horizontal section on $z z'$ (Fig. 282). The fire is placed on a grate g, surrounded by a cast-iron cylinder A, cased with fire-bricks to a certain height. The smoke descends

Fig. 283.

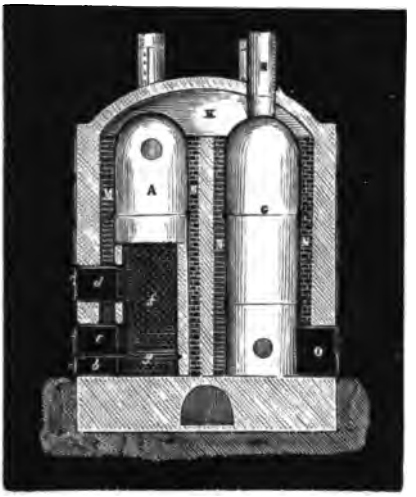
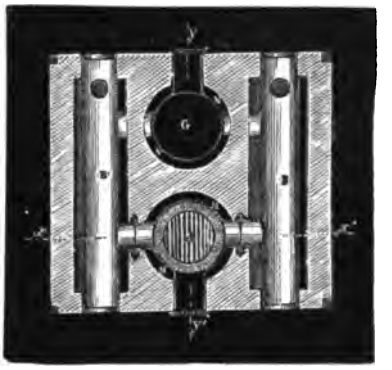
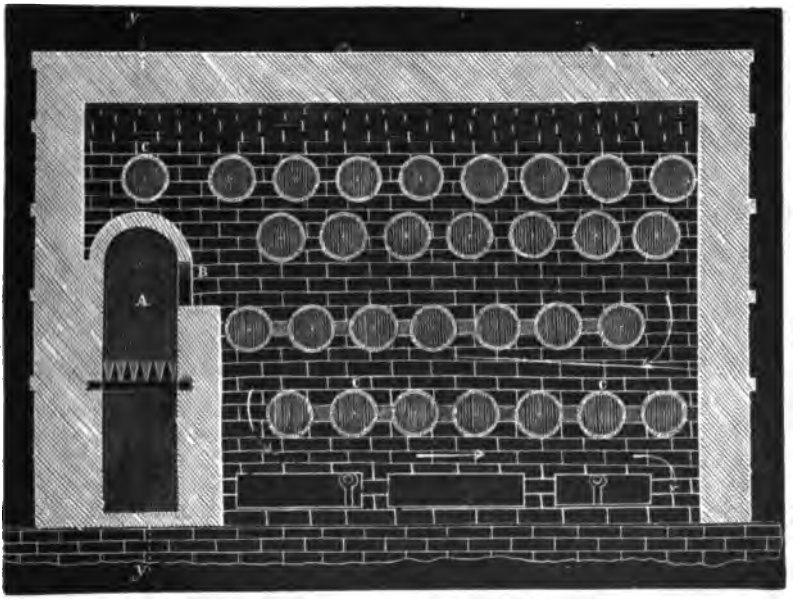


Fig. 284.



simultaneously through the two rows of horizontal pipes *B C D E F* and *B′ C′ D′ E′ F′*, and rises again in the cylinder *G* before passing off by the chimney *H*. The air to be heated is conducted to the stove by the subterranean flues *I I*, ascends at the sides of the two cylinders and round the pipes, collecting at the top of the stove in the chamber *K*, whence it is distributed to the different apartments. The pipes are all of cast iron, connected

Fig. 285.



together with iron cement. The upper door to the fire-place *d* is used for the supply of fuel, whilst *c* serves for clearing the grate. Anthracite or coke may be burned, and these fuels are indeed preferable in this stove, as they do not produce so much smoke, and the pipes require less frequent cleansing. The fire is renewed every seven or eight hours. In order to assist the draught on first lighting the fire after the apparatus has been long out of use, a small additional fire-place is inserted in the cylinder *G*.

The hot-air stoves employed at the Chambre des Députés, in Paris, were constructed by MM. Rohaut and Musard, according to the plans of M. Talabot. They were found to answer perfectly, and continued in action several years without requiring repair. Two were generally placed together, the fires being in the centre, and the chambers containing the air-pipes on each side. Fig. 285 is a vertical section of a single stove on the line *z z'* (Fig. 286). Fig. 286 is a vertical section on the line *y y'* (Fig. 285 and Fig. 287); a vertical section on an undulating plane *x x'* (Fig. 285). *A* is the fire-place, arched over at the top and perforated at *B B* for the escape of the flame and smoke, which, reverberating above and among the two upper rows of cast-iron pipe *C*, are forced by the solid brickwork, which fills up the spaces between the two lower layers, to make their escape in the direction of the arrows to an underground flue. The fire-place is about 3.3 feet long, 2 feet high, and 1 foot wide, and consumes 22 lbs. of coal per hour. The whole chamber, including the fire-place, is about 9 feet 9 inches long by 5 feet wide, and 6 feet 6 inches high. The air warmed by its passage through the horizontal pipes, which are between 6 and 7 inches in

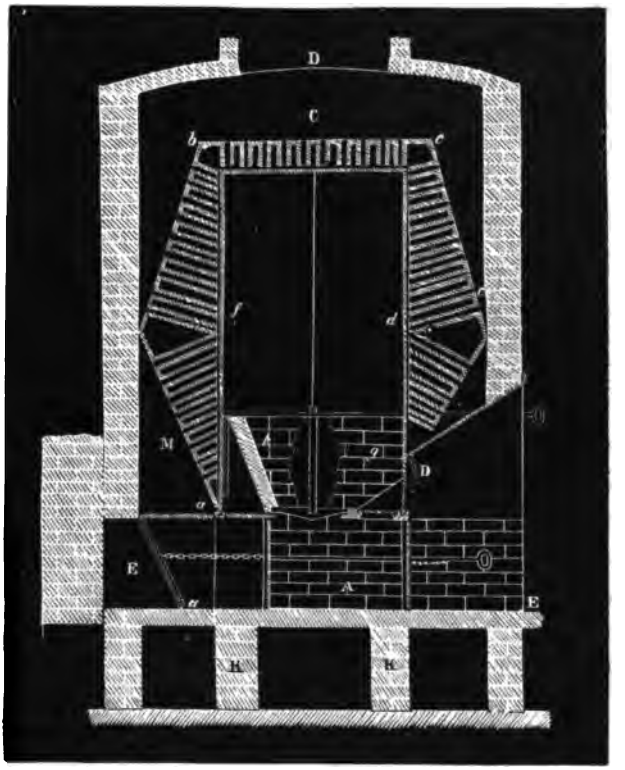
FIG. 286.

FIG. 287.

diameter, has no perceptible odour, very few of the pipes being so near the fire as to become red hot even when the draught is strong. Mr. Constantine states, however (see his treatise on Practical Ventilation and Warming, Churchills), that he found the drawback to the use of this form of stove to be that the pipes frequently were burned through, and with a strong draught this might take place in a few days. He consequently discarded its use in his work. The temperature of the escaping gases is low, although

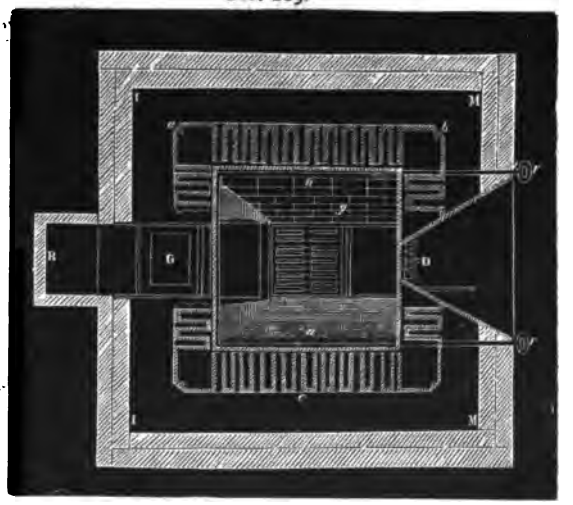
the draught is good and the combustion very complete, even when the ash-pits are nearly closed. Much air finds its way through crevices in the brickwork into the chamber, and there is consequently no fear of smoke being mingled with the hot-air current. Internal ribs to the cast-iron pipes would increase the heating power of the apparatus.

Fig. 288.



A hot-air stove, similar in principle to that used in the general Derbyshire Hospital, but somewhat modified in the construction, is shown in Figs. 288 and 289. A cast-iron cylinder, or cockle, closed at one end, *f*, *d*, descending as low as the grate, is inverted over a quadrangular fire-place in the form of a hopper, and lined with fire-bricks. Fuel is introduced through the door *D*, and the smoke escapes through two long flues running the whole length of the furnace just above the fire at *n n*, and passing between the external brickwork and the cylinder, heats the lower part of the latter before reaching an underground flue leading to the chimney; *r r* are the handles of scrapers for cleaning the flues *n n* when they become choked with soot. *A* is the ash-pit. Fresh air is supplied from the outside of the building by a subterranean channel passing between the walls *K K*. A revolving cowl

Fig. 289.



is attached to the entrance of this channel, the mouth of which is always presented to the wind. The cast-iron cylinder, *f d*, is encased with a sheet-iron envelope, *a b c*, in which are inserted a great number of sheet-iron pipes open at both ends, and terminating within about half an inch of the cast-iron cylinder. Fresh air from between *K K* first ascends into the space *M*, enters the tubes, and, coming in contact with the cylinder, is warmed, and escapes again through the upper series of tubes to the hot-air chamber, whence it is distributed over the building. These hot-air stoves cannot be economical, as little more than the radiant heat is employed in heating the air.

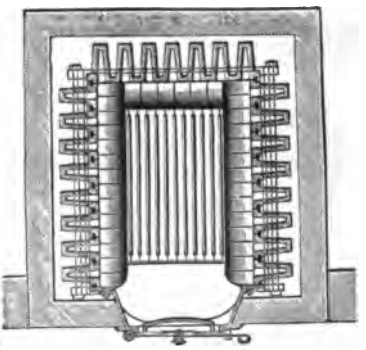
Fig. 290.

Where only a moderate heat is required for a large body of air, the stoves with horizontal air-pipes will be found most useful; their construction is simple, they admit of being easily cleaned or repaired, and are less costly than the others. The cold air, streaming simultaneously through a number of tubes, cools the smoke very effectually, and prevents the tubes from acquiring an excessive heat. A much higher temperature is obtained with the same amount of fuel when the air-current is made to travel in an opposite direction to that of the smoke, as in the stove of René Duvoir.

Figs. 290 to 294 illustrate the "convoluted stove" patented by Messrs. Joseph Constantine & Son, of Manchester, and applied to the heating of large buildings, such as the Manchester Royal Exchange, Concert Hall, Pantechnicon, Theatre Royal, &c., and to supplying hot air in the Arlington Street Turkish Baths in Glasgow and at other baths.

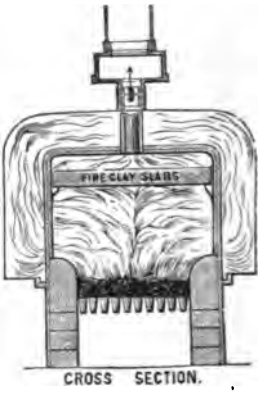
Fig. 290 shows an elevation of the ironwork of the stove without the brick

Fig. 291.



HORIZONTAL SECTION.

Fig. 292.

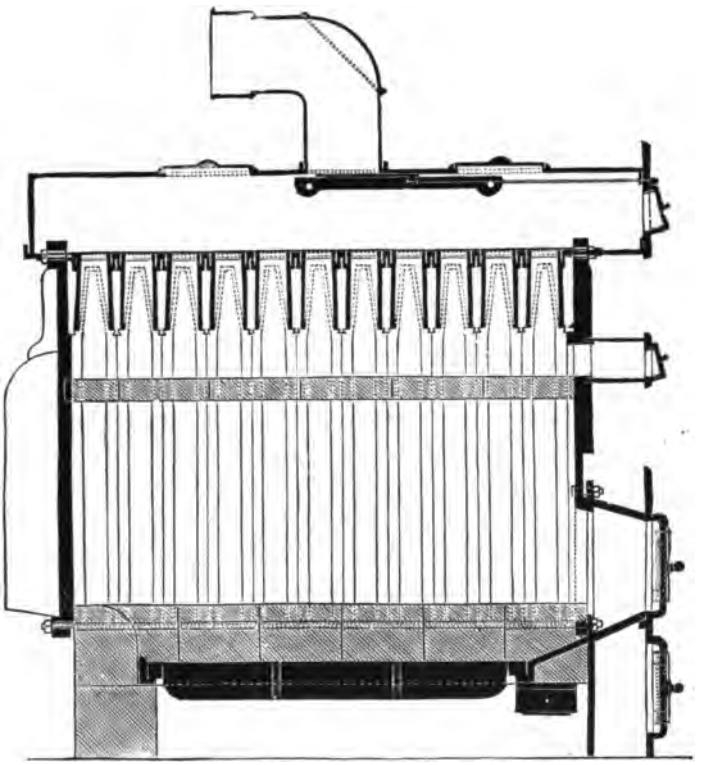


CROSS SECTION.

casing which forms the air-circulating space. Fig. 291 is a horizontal section of the stove and casing, and Fig. 292 is a cross section of the stove alone. Fig. 293 shows a sectional elevation at right angles to Fig. 292. At Fig. 294 the stove is shown in perspective inside the brick casing, a portion of which has been removed to show the stove in position, and the cold-air and hot-air flues.

This stove is formed on the model of the well-known "gill" stove, but with the flanges or "gills" made hollow, so that the flame and hot gases are in contact with the outermost surface of the projections. Like the gill stove, it is made in sections, which are bolted together to form any desired depth of body. The "convolutes" are "slightly arched or dome-shaped, each being deeply grooved to form a chamber, with an aperture at the top of each arch leading to the smoke-box. These grooves extend also down the sides. Each convolute is a separate casting, and is in itself a moderate-sized stove, the inner and outer surface being equal. The convolutes are held together by bolts (shown in Figs. 290 and 291), and are connected by a peculiar hermetical joint invented by Mr. Constantine, and made tight by the use of iron borings." In order to diffuse the hot gases and flame into the grooves

Fig. 293.



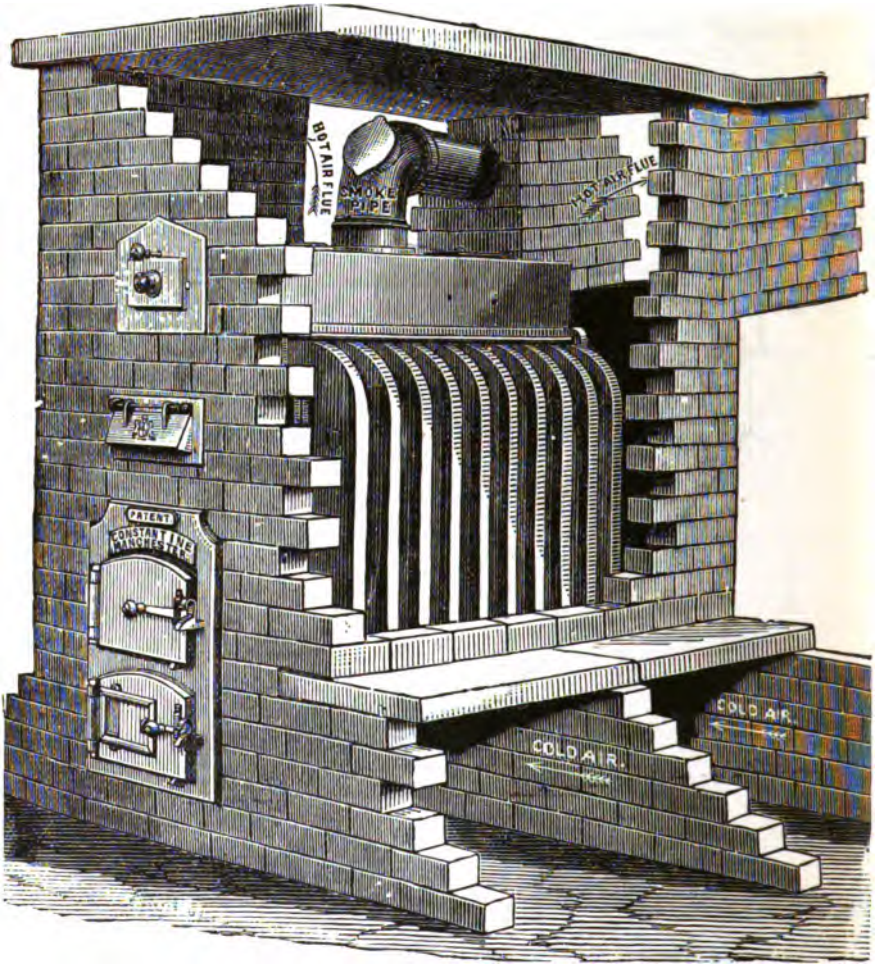
or convolutes, and to prevent the too rapid escape of the heat by the chimney, fire-brick slabs are placed in brackets across the fire-space, and form a roof to the combustion chamber, or baffle-plate to the flame. These slabs are shown in the cross-section Fig. 292. They equalize the temperature in the stove, and project the flame and hot gases into the convolutes where they are wanted. Fire-brick is also used to protect the iron from the immediate action of the fire at the sides and back near the grate-bars.

The proportion of heating- to grate-surface is large in these stoves, being about 100 to 1, and affords security against overheating the stove.

The results of heating by means of these stoves are very satisfactory. The Manchester Royal Exchange has an area of 1,500,000 cubic feet, and is kept

at a uniform temperature of 50 to 56° F by the expenditure of 2½ cwts. of coke per twenty-four hours. From its great area (the ground covered being some 5,400 square yards), the warming of this Exchange was a problem which is said to have caused considerable anxiety, but the successful warming of the Free Trade Hall in Manchester by the convoluted stove led to its adoption in the Royal Exchange. Two large stoves fixed in the basement were found to answer the purpose effectually, and with less labour and fuel than are required for many small churches under other systems.

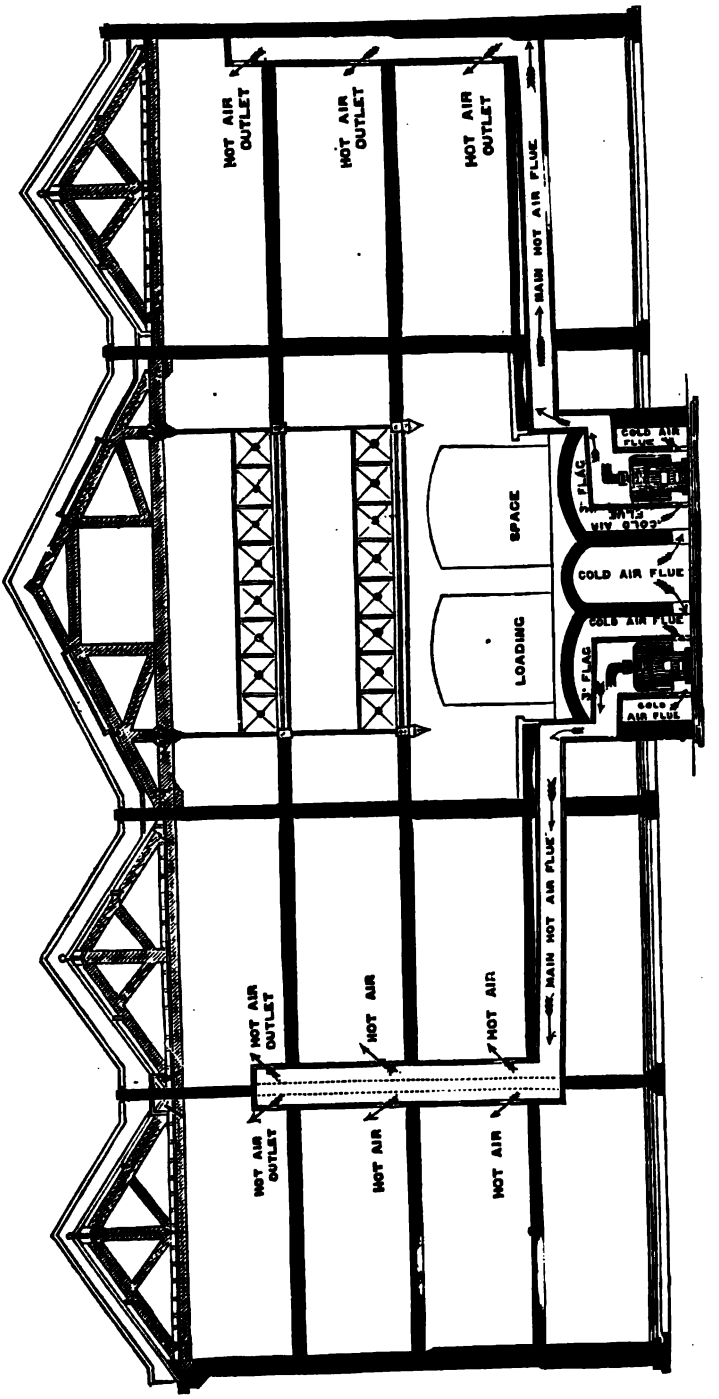
Fig. 294.



The arrangement is simple. Fresh air is drawn from the top of the building down a shaft of about 6 feet square, through a cold-air chamber at the bottom, in which it is filtered, and is then passed through the warming chamber to two flues which run the full length of the hall, with branch flues into the plinths of the columns, from which the warm air is delivered.

The quantity and cost of coke consumed during a period of seven years are as follows :—

FIG. 295.

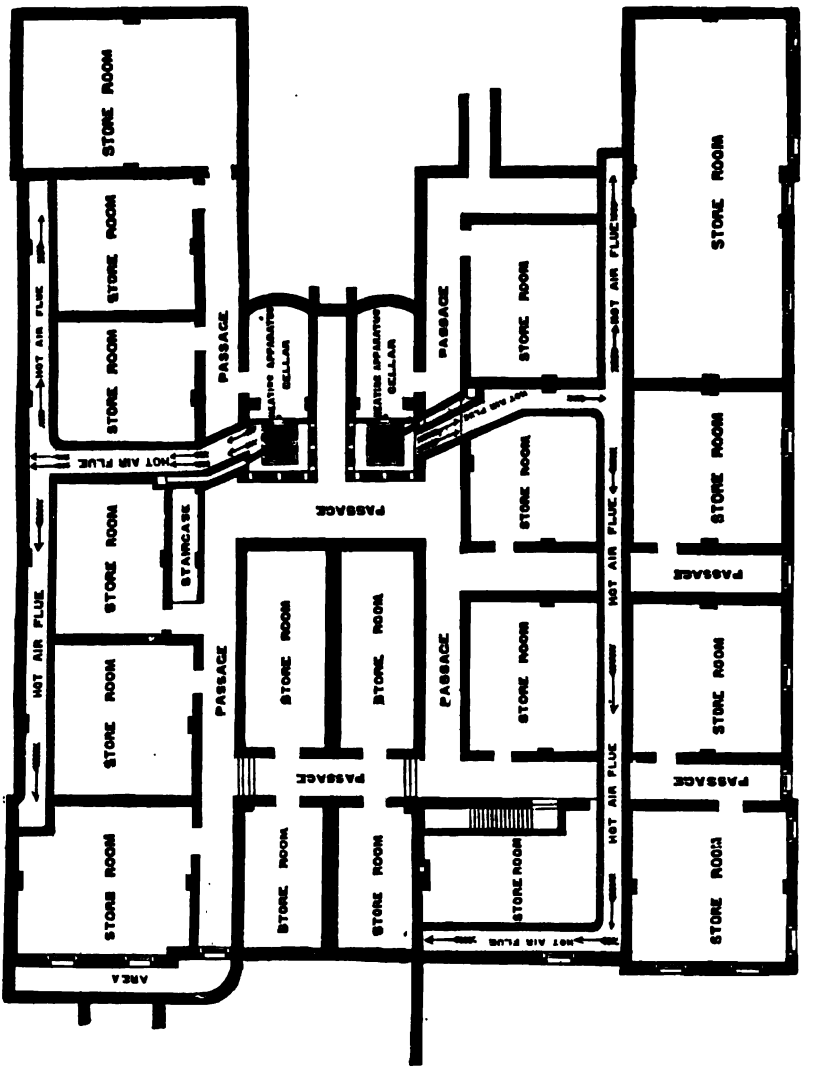

HOT AIR OUTLET
HOT AIR OUTLET
HOT AIR OUTLET
MAIN HOT AIR FLUE
COLD AIR FLUE
SPACE
LOADING
COLD AIR FLUE
COLD AIR FLUE
HOT AIR OUTLET
HOT AIR
HOT AIR
HOT AIR OUTLET
HOT AIR
HOT AIR
MAIN HOT AIR FLUE

Year.	Tons.		£	s.	d.
1874-75	28	...	10	10	0
1875-76	21¼	...	8	1	3
1876-77	22¾	...	8	10	7½
1877-78	19¾	...	7	8	1½
1878-79	31¼	...	11	14	4½
1879-80	21	...	7	17	6
1880-81	20	...	7	10	0
Total for 7 years	164¼	tons, costing	£61	11	10½

or an average cost of £8 16*s.* per annum for fuel.

The Manchester Pantechnicon, of which Fig. 295 shows a sectional elevation and Fig. 296 a basement plan, with a floor area, devoted to storage

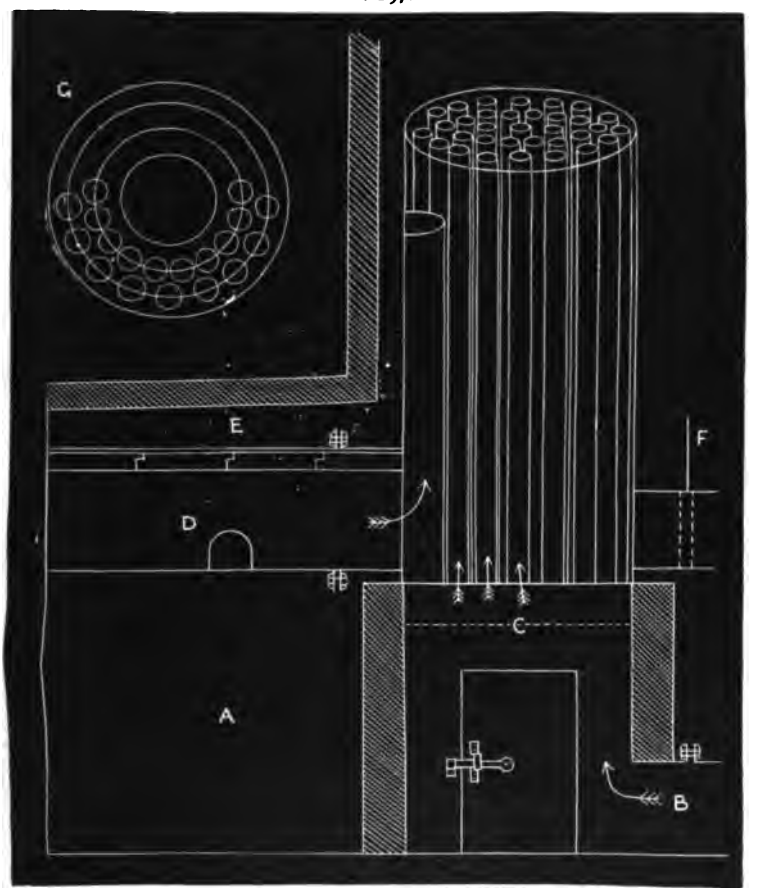
Fig. 296.



purposes, of 90,000 square feet, is warmed at a cost of little over £10 per annum. The illustrations give an idea of the extent to which the heated air must be distributed in this case.

At the Arlington Baths * in Glasgow, the hot air for the Turkish bath is supplied by these stoves. "The cubic capacity of the hot and hottest rooms is about 17,700 feet, giving a proportion of 1 square foot of cast-iron heating-surface in the stoves to about 23.8 cubic feet of contained space." "The

FIG. 297.



heating and ventilation of these rooms (with the necessary shampooing-room) is obtained by a consumption of from 48 to 60 cwts. of gas coke per week of fifty-five hours."

The Turkish baths at Llandudno Hydropathic Establishment are also heated by these stoves at a fifth of the cost of the plan formerly employed there, the temperature of the hot rooms being maintained at 200° F. instead of 150° F., as formerly was the case, and the ventilation being said to be excellent.

Coke being the fuel generally employed in these stoves, no smoke is produced in working them.

* See J. L. Bruce, On the Heating and Ventilation of Turkish Baths, "Proc. Phil. Soc. Glasgow;" also J. Constantine, on "Practical Ventilation and Warming," p. 77 (London: Churchill).

Another hot-air stove successfully introduced into Turkish baths is the multitubular heating stove invented by Mr. John Bissett, clubmaster at the Victoria Baths, Glasgow, and illustrated in Fig. 297. The furnace and combustion chamber, the latter separated from the grate by a bridge of fire-brick, are distinct from the chamber containing the vertical wrought-iron heating-tubes, so that the tubes do not come in contact with the fuel, or even with flame. The roof of the furnace is used as heating-surface, as well as the outside casing which encloses the tubes, whilst air is heated also by passing upwards inside the tubes. The flame is kept from striking on the tubes by a baffle-plate, which directs the hot products of combustion to the top of the chamber containing the tubes. From this point, the gases have to descend in contact with the outside of the tubes until the flue leading to the chimney is reached.

In the illustration Fig. 297, D is the fire-brick bridge between the grate and the combustion chamber. The flame and hot gases escape upwards, as shown by the arrow, to the top of the chamber containing the vertical tubes, and then descend in contact with the exterior surface of the tubes to the chimney flue and damper, F. A is the ash-pit. Cold air enters at B, and ascends the vertical tubes, entering them as the arrows indicate at C. Air is also heated in the space E above the fire-brick roof of the furnace. G shows the tubular chamber in sectional plan.

The stove is put together with a view to facility in carrying out repairs when necessary, and it gives good results at the Turkish baths of the Victoria Baths Company. The hot room in these baths has a capacity of about 9,000 cubic feet, and is heated to 150° F. in little more than an hour. The stove used for this room is 5 feet by 2 feet 9 inches, with 100 tubes of 2 inches diameter. The hottest room is heated to 200° F. by a stove of fifty-five 2-inch tubes 4 feet high. These stoves are in operation from 90 to 100 hours per week, and in winter use in that time between them 20 cwts. of gas coke—in summer much less. The temperatures are maintained in the rooms very steadily, and the ventilation of the rooms is excellent.

The various modifications which have been adopted for raising air to a high temperature are very numerous, and it is impossible to give illustrations even of all that have been most generally employed. Herder's *Erwärmung der Gebläseluft*, and Péclet *Sur la Chaleur*, contain numerous details of the mode of applying the hot blast to lead and iron smelting.

Hot-blast Stoves.—The application of hot air to iron smelting is of far greater importance than any use of heated air for warming or ventilating buildings. The introduction of hot blast caused a revolution in the practice of the smelting process, which resulted in an enormous increase in the manufacture of iron, whilst the quantity of fuel used per ton of iron was very greatly reduced. Mushet* stated that in Scotland the amount of the saving in quantity of coal used in the blast furnace was not less than 100 per cent., but that the coals in that quarter do not on an average contain more than 50 per cent. of carbon. In South Wales the saving did not exceed 25 per cent., where the coals contain from 80 to 90 per cent. of carbon. So all over England it was found that the saving was intimately connected with the percentage of carbon in the coal. And this, remarks Mr. Mushet, is a rule which in the very nature of things ought to exist, for, after all, it is not the volume of coals alone which is the point for consideration, but the quantity of solid matter of fuel—viz., the carbon which is present in it.

The results in quantity of pig-iron produced per furnace per week, and in quantity of fuel used per ton of iron produced, during three periods at the Clyde Ironworks, the blowing engine having been the same in all, were

* "Papers on Iron and Steel," 1840, p. 310.

compared by Dr. Clark in a paper* quoted by Dr. Percy. The periods referred to are—the first six months of 1829, when cold blast was exclusively used with coke as fuel; the first six months of the following year, when the blast was heated to 300° F., coke being still used; and the first six months of 1833, when raw coal was used in the furnaces, the blast having been heated to 600° F. The following are the results:—

Coke and Cold Blast. From Jan. 7 to Aug. 19, 1829.		Coke and Hot Blast 300° F. From Jan. 6 to June 30, 1830.		Coal and Hot Blast 600° F. From Jan. 9 to June 30, 1833.	
Average Weekly Make of Pig-iron in Three Furnaces.	Average Consumption of Coal per Ton of Pig-iron.	Average Weekly Make of Pig-iron in Three Furnaces.	Average Consumption of Coal per Ton of Pig-iron.	Average Weekly Make of Pig-iron in Four Furnaces.	Average Consumption of Coal per Ton of Pig-iron.
Tons cwts. qrs.	Tons cwts. qrs.	Tons cwts. qrs.	Tons cwts. qrs.	Tons cwts. qrs.	Tons cwts. qrs.
110 14 2	8 1 1	162 2 2	5 3 1	245 0 0	2 5 1

It appears from these results,† Dr. Percy remarks, that by the application of hot blast the same amount of fuel reduced three times as much iron, and the same amount of blast did twice as much work as previously.

Such extraordinary results could not fail to direct attention to the difference in the nature of the combustion produced under the two sets of conditions, so that we may say that the introduction of hot blast has led to considerable advance in the understanding of the theory and practice of combustion.

Prior to the introduction of this invention it is evident‡ that very crude ideas prevailed both as regards the theory of smelting and as regards the part played by the air used in combustion. The difference between *amount* of heat and calorific intensity, or the *temperature* of combustion, was not recognized, nor did any one take into account the absorption of heat caused by the expansion of air on its being heated inside a furnace. The efficacy of the combustion in blast furnaces was supposed to depend on the absence of moisture in quantity in the blast, better combustion being obtained in the frost of winter, and this led ironmasters to cool the blast as much as possible, even employing methods which defeated their end as to freedom from moisture.

For a long time after the subject became better understood, the prevailing opinion was that the results obtained with hot blast are due to the higher temperature and greater activity of combustion occasioned by its use. As heat is not abstracted in this case by the expansion of the air, nor by heating up the carbon and oxygen to the temperature of combustion, except through a small range, the full value of the temperature produced by the union of hot carbon and hot oxygen is realized—a higher temperature of combustion is available, and the chemical union which we call combustion proceeds more rapidly, so that there is also a larger amount of heat available. The effects of this high temperature in the zone of combustion extend to a considerable height in the furnace, causing the quicker reduction of the oxides of iron to the metallic state, and also the heating up of the solid materials previous to their entrance into the zone of intense combustion.

There is much force in this view of the matter, which is still held by the advocates of very hot blast.

Sir Isaac Lowthian Bell has, however, introduced some important considerations which cannot be ignored in dealing with the subject, the effect

* On the Application of the Hot Blast in the Manufacture of Cast Iron, by Dr. Clark, Prof. of Chemistry at Aberdeen, "Proc. Roy. Soc. Edin.," March 16, 1835.

† See also Mushet, "Papers on Iron and Steel," Appendix, pp. 909-923.

‡ Mushet, *op. cit.*, Preface, p. xvi.; also pp. 321 *et seq.*

of which is to modify considerably all the generally accepted ideas as to the value of higher temperatures of blast, or even of hot blast at all, as compared with cold air. This we shall refer to farther on.

Mr. Neilson, the inventor of the hot-blast system, has left on record* an account of the circumstances which led him to the idea. "Six or seven years," he said, "before he brought out the plan, he had read a paper before the Glasgow Philosophical Society on the best mode of taking out the moisture from the atmospheric air in summer time, previous to its entrance into the furnace through the tuyeres; for it was found that the make of iron was much impaired in summer weather, both in quality and quantity, and he had become satisfied that the cause lay in the greater proportion of moisture contained in the air at that season. His first idea was to pass the air through two long tunnels containing calcined lime, so as to dry it thoroughly on its way to the blast cylinder of the blowing engine; but this plan was not put to trial. About that time his advice was asked in regard to a blast furnace, situated at a distance of half a mile from the blowing engine, which did not obtain a sufficient supply of blast at that distance, and consequently did not make so much iron as two similar furnaces situated close by the same engine; and it then occurred to him that since air increases in volume according to its temperature, if it were passed through a red-hot vessel before entering the distant furnace its volume would be increased and it might be enabled to do more duty in the distant furnace. Being at that time engaged in the Glasgow Gasworks, he made an experiment at once on the effect produced on the illuminating power of gas by a supply of heated air brought up by a tube close to the gas-burner, and found that by this means the combustion of the gas was rendered more perfect and intense, so that the illuminating power of the particles of carbon in the gas was greatly augmented. He then tried a similar experiment with a common smith's fire, by blowing the fire with heated air; the effect was that the fire was rendered most brilliant, with an intense degree of heat, while another fire blown with cold air showed only the brightness ordinarily seen with a high heat. Having obtained such marked results in these small experiments, it then occurred to him that a similar increase in intensity of combustion and temperature produced would attend the application of the same plan on a large scale to the blast furnace; but his great difficulty in further developing the idea was that he was only a gas-maker, and could not persuade iron-masters to allow him to make the necessary experiments with blast furnaces at work. At that time there was great need of improvement in the working of blast furnaces, for many furnaces were at a stand for want of blast, being unable to maintain the necessary heat for smelting the iron; and, unless as much as £6 per ton could be obtained for the iron, no profit was realized, on account of the heavy expenses attending the furnaces. A strong prejudice was felt against any meddling with the furnace, and a kind of superstitious dread of any change prevailed, from the great ignorance of furnace managers with respect to the real action going on in the furnace, and the causes of the fluctuations that occurred. When a furnace was making No. 1 iron, no one would be allowed to touch it, for fear that if any change took place it might be many weeks before the furnace got round again from white iron." He at length succeeded in getting an opportunity of trying the application of heated air for blowing a furnace at Clyde Ironworks, near Glasgow, and, though the temperature of the air was raised not more than about 50° F., he was glad to be able to make a trial even with so small an amount of heat. This first imperfect trial, however, showed a marked difference in the scoria from the furnace, which was less black and contained less iron; and he was therefore anxious to try the plan on a more extended

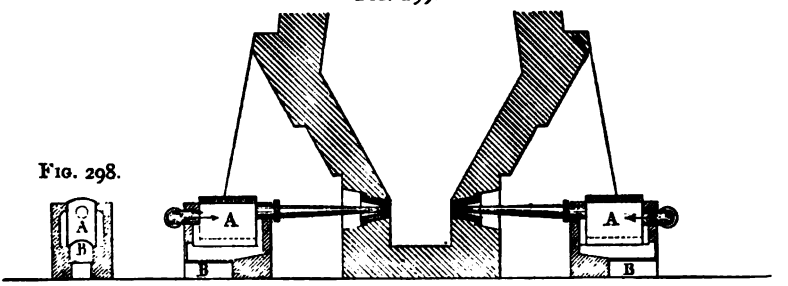
* "Proc. Inst. Mech. Eng.," 1859, p. 98.

scale, which, after some years of struggling with perseverance against the prejudices of ironmasters, he was at length enabled to do at Clyde Ironworks.

The first apparatus for heating the blast which was used at Clyde Ironworks early in 1829* is illustrated by Figs. 298 and 299, the latter being a transverse section of the apparatus. "It consisted," according to Mr.

FIG. 299.

FIG. 298.

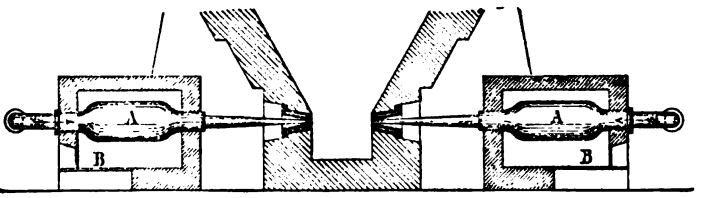


Henry Marten's description, "of a small wrought-iron heating chamber, A, Figs. 298, 299, about 4 feet long, 3 feet high, and 2 feet wide, in construction similar to a waggon-head steam boiler, which was set in brickwork with a grate, B, below," as was also the arrangement in the old-fashioned steam boiler. "The cold blast entered at the end immediately over the grate, and passed out to the tuyere from the other end, being warmed in its passage along the chamber to a temperature of about 200° F. There was one of these heating chambers to each tuyere; the total area of fire-grate per tuyere was about 4 square feet, and the area of heating surface of the chamber 35 square feet." This apparatus, though successful in heating the blast through a short range of temperature, proved not durable, as the boiler-plates forming the chambers A A quickly oxidized, or, in fact, were burned through, under the influence of the air and the red heat to which they were exposed.

Mr. Neilson's experience with cast-iron retorts in the gasworks having shown him the greater durability of cast-iron when exposed to high temperatures, he soon substituted cast-iron retort-shaped heating vessels for the chambers A A.

This arrangement is shown in Fig. 300, and "was found to be a great

FIG. 300.



improvement on the original plan, lasting longer and raising the temperature of the blast to about 280° F. It was constructed at Clyde Ironworks about the end of 1829." These heating vessels were "cylindrical cast-iron tubes, A (Fig. 300), shaped like a bottle-neck at each end for the admission and discharge of the blast. They were about 2 feet 9 inches diameter and 6 feet long. As in the former case, there was one of these vessels to each tuyere, but the heating surface was increased to 55 square feet per tuyere, or one

* See Henry Marten, On Hot-blast Ovens, "Proc. Inst. Mech. Eng.," 1859, pp. 62–86.

and a half times the surface exposed in the first application, and the grate area was increased to 11 square feet, or nearly three times." A further improvement consisted in wholly enclosing the heating vessel in the heating furnace, the roof of the chamber having been in the former case exposed to the atmosphere.

In the arrangement carried out at Clyde Works in 1830, and shown in Figs. 301 and 302, there was a great advance made in the direction of increased

FIG. 301.

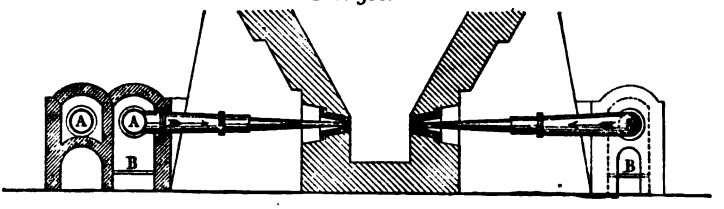
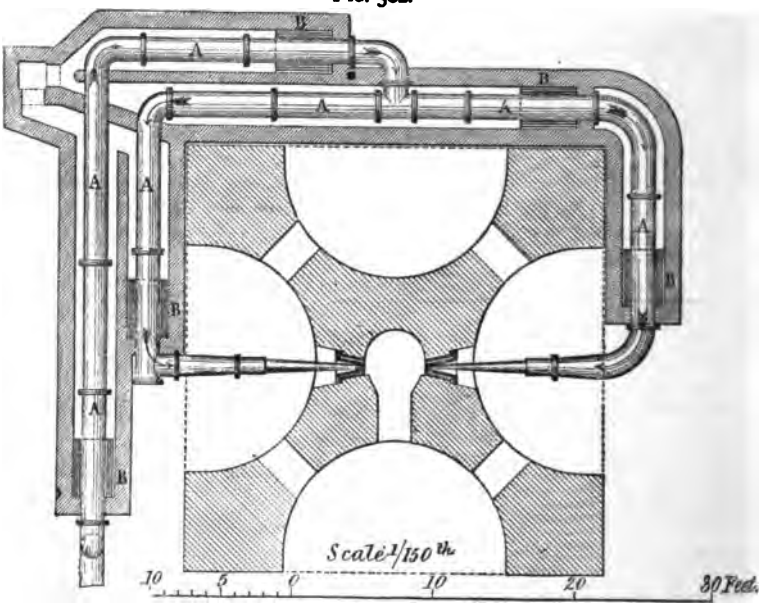


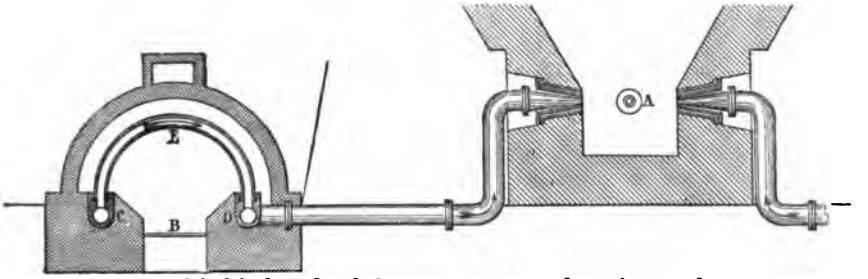
FIG. 302.



efficiency. The grate area was increased to 28 square feet per tuyere, five grates, B B, being employed for two tuyeres. The heating chamber was formed of cast-iron pipes, A, of 18 inches diameter, completely enclosed in flues, and having a total length of about 100 feet, giving 240 square feet of heating-surface area per tuyere. The temperature of blast obtained by means of this arrangement was fully 600° F., lead having been melted by the heated air. So great an improvement was realized in both the quality of the produce and the yield of the furnace worked under these new conditions that furnace managers were encouraged to overcome difficulties in working and defects in arrangement which continued to manifest themselves. The elevation of the temperature caused severe strains to be thrown upon the metal of the stoves wherever inequality of heating was produced, because irregular expansion and contraction and durability were not as yet provided for in the form given to the stove.

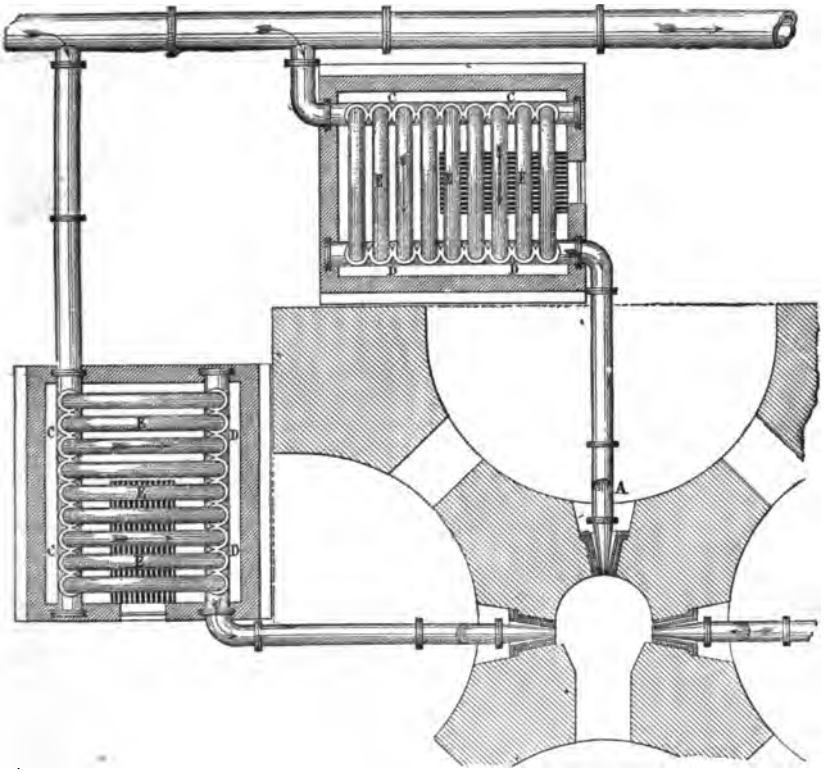
The first hot-blast stove or oven properly so called, constructed of cast-iron bent or arched pipes, was erected by Neilson, at Clyde Ironworks, in 1832, and is shown in Figs. 303 and 304. "In this case the irregular fire-grates, five to two tuyeres, were done away with, and an oven with one grate only

FIG. 303.



was constructed behind each of the tuyeres, now three in number, a tuyere, A, being at this time inserted at the back of the furnace in addition to the two, one on each side, which were used before the introduction of hot blast. In the oven now constructed the blast, instead of being carried, as formerly,

FIG. 304.



along one continuous heating-tube directly over the grate, was admitted into a main pipe, C, running longitudinally at one side of the grate B. On the top of this main pipe a number of deep circular sockets were cast, with apertures into the pipe, and on the opposite side of the grate a similar main

pipe, D, was fixed, with corresponding sockets and apertures, which was connected with the tuyere-pipe inserted into the furnace. The two longitudinal main pipes, C and D, on each side of the grate were then connected by cast-iron tubes, E, each forming a semicircular arch of 6-feet span. fastened into the sockets with well-rammed iron cement. The cold blast was supplied to each of the ovens by a branch pipe taken direct off the large main from the blast engine, and entered the oven at the end farthest from the grate. It then passed through the arched tubes E, over the fire, into the pipe D, on the other side of the grate, and thence to the tuyere, leaving the oven at the end next the grate.

"The whole of the apparatus was enclosed in an arched brick oven, so as to retain and reverberate as much heat as possible.

"The general dimensions of the apparatus for each tuyere were as follows:—

"Diameter of longitudinal mains at each side of grate	12 ins.
Length of " " " "	10 ft.
Distance between longitudinal mains, centre to centre	6 "
Number of arched connecting tubes	9
Internal diameter of " "	4 ins.
External " " "	7 "
Height from grate to under-side of arched tubes	4 ft. 4 "
Area of heating-surface per tuyere	150 sq. ft.
" fire-grate per tuyere	15 "

"On comparing this with the previous plan shown in Figs. 301 and 302, it will be observed that this apparatus, owing to its improved construction, maintained as efficient a temperature with less than two-thirds of the heating surface per tuyere and a little more than half the grate area."

Further experience of this apparatus showed that improvement was still required, and, for a considerable number of years subsequent to the introduction of this oven of Neilson's, new forms were tried both by Mr. Neilson and by his licensees in various parts of the country. "In 1834, Messrs. Lloyds, Fosters, & Co., of Wednesbury, erected an apparatus at their works for heating the blast, and singularly enough, at that early period, proposed to apply the waste gases from the tunnel-head for this purpose." This apparatus "consisted of a circular wrought-iron heating chamber placed within the brickwork of the tunnel-head, the flame from the furnace rising up through the centre of the chamber. The blast was supplied into it from the cold main through several small apertures, which distributed the air against the plates of the chamber on the side exposed to the action of the flame, and the hot blast was conveyed in a pipe down to the tuyeres. This apparatus was very expensive in its first construction, and constantly required repairs. It produced a heat of only about 360° F., so that a small supplementary oven was required near the tuyere to raise the temperature of the blast still further previous to its entrance into the furnace." Consequently this plan was soon abandoned.

In order to remedy the burning of the arched pipes of the oven illustrated in Figs. 303 and 304, ovens were constructed at Calder Ironworks and by Mr. Firmstone at Lay's Ironworks, near Dudley, on an improved plan. The arched tubes were elongated into the form of siphon pipes, and in some instances carried to a height of 10 feet above the main. As an additional safeguard, at Lay's Ironworks the grate was placed in a separate compartment, and the hot gases were passed into the oven through small narrow apertures between the horizontal mains.

At this stage, the plan of having a separate oven for each tuyere was abandoned, and the general heating capacity was so much increased that

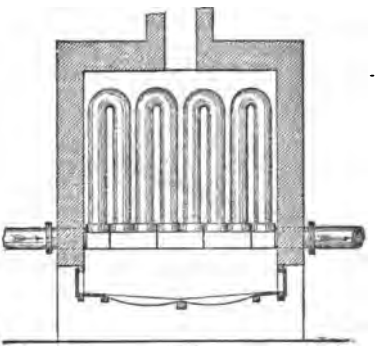
one oven of the following dimensions was found to be capable of heating the blast for three tuyeres to a temperature of 600° F. :—

Length of longitudinal mains	7 ft. 6 ins.
Number of siphon pipes	9
Area of direct heating surface, total	240 sq. ft.
„ „ „ per tuyere	80 „
Area of fire-grate, total	9 „
„ „ per tuyere	3 „

Several continuous-pipe ovens were designed about 1836 and tried for a time. One of these had horizontal pipes in two tiers with sharp round bends forming a zigzag path for the air. This was erected in 1836 at Dowlais Ironworks, in South Wales, and had a heating surface of 9 square feet giving a blast temperature of 300° F.

A spiral-pipe oven was erected at Ebbw Vale Ironworks, and was heated by the waste gases from the furnace. It worked well, maintained a good heat, and was seldom out of repair, but it involved the inherent defect of all continuous-pipe ovens, which was the great loss of pressure of blast by friction in consequence of the whole of the blast having to pass at a rapid rate through a single pipe.

Fig. 305.



The box-foot oven erected in North Staffordshire and at Ystalyfera, at the latter being fired by the waste furnace gases, is shown in Figs. 305 and 306. This was another good form of the continuous pipe oven, against which the greatest objection was the loss of pressure of blast through friction. It consisted of "a series of separate cast-iron foot-boxes placed in the position of the longitudinal main on each side of the grate. Each box was provided with two sockets cast on the upper side, excepting the two boxes at each end of the oven, which had only one socket, the other end of these boxes communicating with the inlet or outlet pipe. Cast-iron siphon pipes were erected in the oven, each pipe footing in adjoining boxes, and the blast, entering the oven at one end, had to pass up and down alternately through the whole series of siphon pipes before leaving the oven at the other end."

Fig. 306.

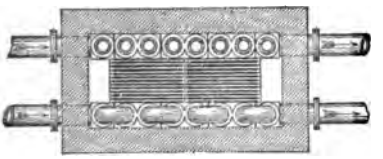


Fig. 307.

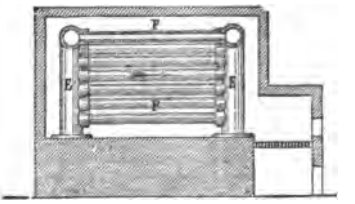
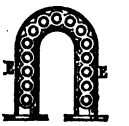


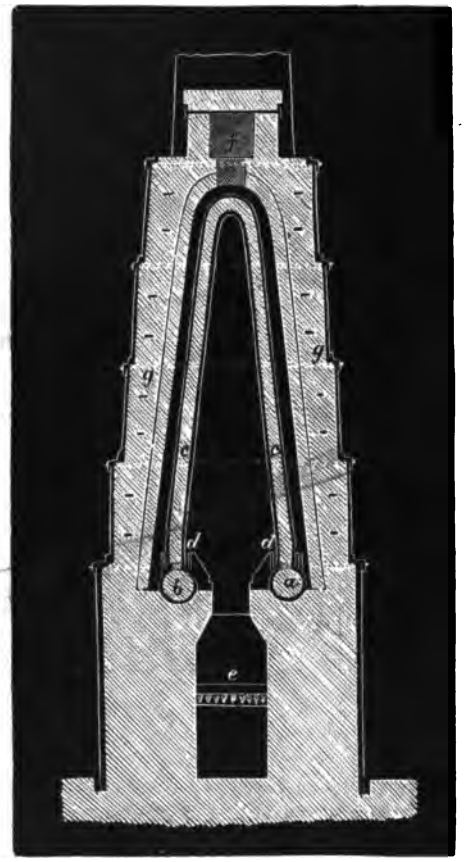
Fig. 308.



Figs. 307 and 308 show a horizontal-pipe oven erected at the Monkland Works, near Airdrie. It consisted of two main vertical pipes, E E, of horse-shoe pattern, with numerous sockets, cast on one face, standing opposite to each other 6 feet apart. Fifteen small straight cast-iron tubes, F, joined these two mains, being inserted in the sockets and tightly jointed there. This design is interesting as being the first example of a curved main, but was not otherwise notable.

A modification of the siphon-pipe stove is shown at Fig. 309, and consisted of two horizontal pipes, *a b*, to the upper surface of which a series of ∩-pipes, *c*, were fixed, as shown in the drawing at *d*, the joints being encased in brickwork. These pipes were heated by a powerful fire, *e*, the flame from which played round the upright pipes, and passed off at *f* through a flue built on the top of the stove. The walls *g* acquired a red-heat, and assisted in maintaining a uniform temperature. The blast in being forced through the apparatus met with a stop-plate in the horizontal pipe *a*, which it entered first; the air ascended the ∩-pipes corresponding with this section, and passed on through the opposite pipe, *b*, until it encountered another stop-plate, when it re-entered another series of ∩-pipes, and thus continued ascending and descending until it had acquired the necessary temperature.

Fig. 309.



This plan of heating the air was not economical; the air-current travelled in a direction contrary to that of the smoke, through only the half of the circuit in the pipes, and the hot gases escaped from the furnace at a very high temperature.

At Codnor Park Ironworks a more advantageous plan of heating the blast was introduced. Two very wide cast-iron pipes, *B* and *D*, Figs. 310 and 311, were set in a furnace in such a manner that the flames should play first over the entire length of the one, and then in the opposite direction over the other, before escaping to the chimney; into each of these, pipes of less diameter, shown at *A* and *C*, were inserted, open at both ends, one end projecting beyond the brickwork of the furnace. The air from the blowing cylinders was admitted into the upper narrow pipe, and, passing to the far end, returned through the annular space between it and the outer pipe; thence it was conducted by a short cross pipe to the annular space between the other lower pipes, and

Fig. 310.

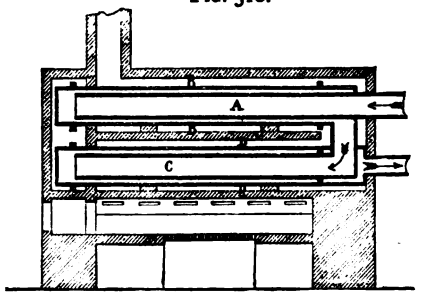
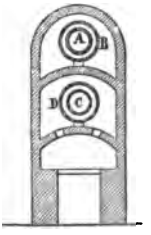


Fig. 311.



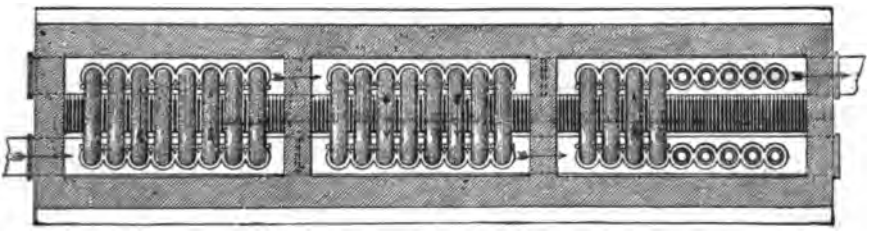
passed to the tuyeres through the second pipe of small diameter. The air thus traversed in the contrary direction to the smoke, and the inner iron pipes were of great value in increasing the heating surface.

The improvement in the manufacture of pig-iron which followed the introduction of the hot blast causing an increase in the quantity made, furnaces were consequently enlarged and larger quantities of blast were required. Ovens of larger capacity were thus rendered necessary, and the introduction of these, in some cases, brought new conditions and new difficulties.

At first double ovens were tried, two ovens of ordinary size being placed either end to end, or side by side, the latter being considered the better from a mechanical point of view, although the former was more frequently adopted on account of other considerations.

Fig. 312 shows the "end on" plan applied to the construction of a triple

FIG. 312.

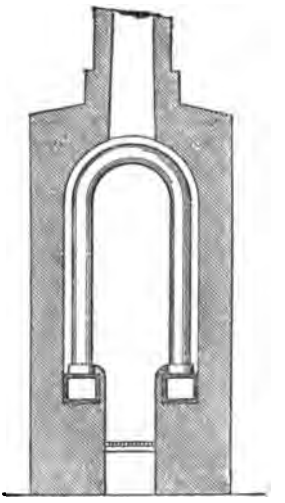


oven, which was a form of long oven ordinarily in use in Staffordshire in early days, from about 1837, when it was first erected.

This oven consisted of twenty-five pipes of circular section having 1,200 square feet of heating surface and 126 square feet of grate area, and was capable of maintaining blast for six tuyeres at 600° F.

In working with large ovens, it soon became necessary to introduce stop valves at each end of the oven for the purpose of isolating any oven for repair or examination, and also for testing the amount of leakage of blast in each oven.

FIG. 313.



Means had also to be provided for checking the sudden increase of heat in the ovens consequent on the stoppage of the blowing engine at casting time.

Even with long siphon pipes the difficulties of expansion caused some trouble, and various sections and arrangements of pipes were tried.*

Fig. 313 shows the form which ultimately was in many cases adopted, and which gave very good results. Fixed main socket-pipes of square section were used, although loose mains had been found to answer admirably; the siphon pipes were of flat oval section, with vertical legs parallel for some distance above the grate or combustion space, instead of inclining towards each other, and connected at the top by a large semicircular arch. This form of siphon pipe stood well, and was neither liable to be burnt near the sockets nor apt to crack at the arch, the strains being distributed over a considerable length.

* See Henry Marten, On Hot-blast Ovens, "Proc. Inst. M.E.," vol. for 1859. pp. 75-79.

The "pistol-pipe" stove is illustrated in Fig. 314, where it is shown as adapted for the use of waste furnace gases in its combustion chamber *b*; and another modification of the rectangular stove used in Lancashire and other parts will be found illustrated in works on metallurgy.* American practice

Fig. 314.

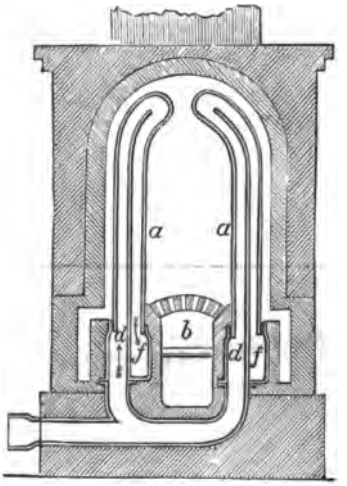


Fig. 315.

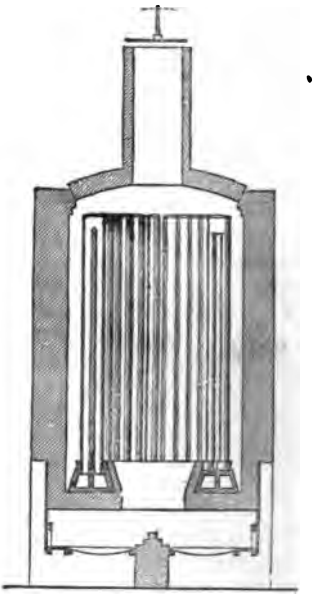


Fig. 316.

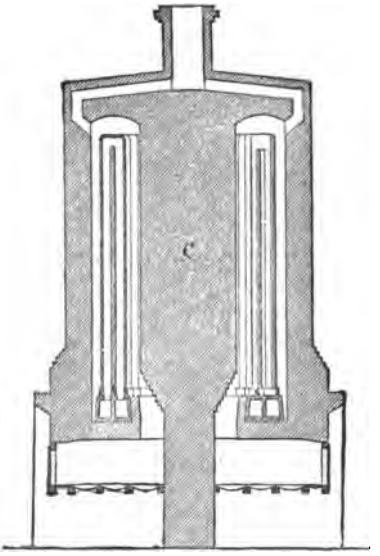
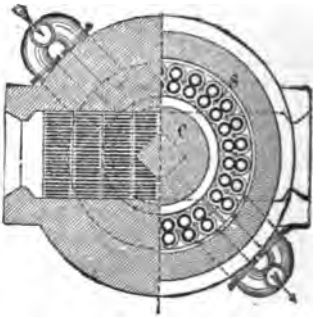


Fig. 317.



will be found illustrated in "American Iron and Steel Works," by A. L. Holley and Lennox Smith.

F. Kohn's "Iron and Steel Manufacture" also contains useful information on this subject.

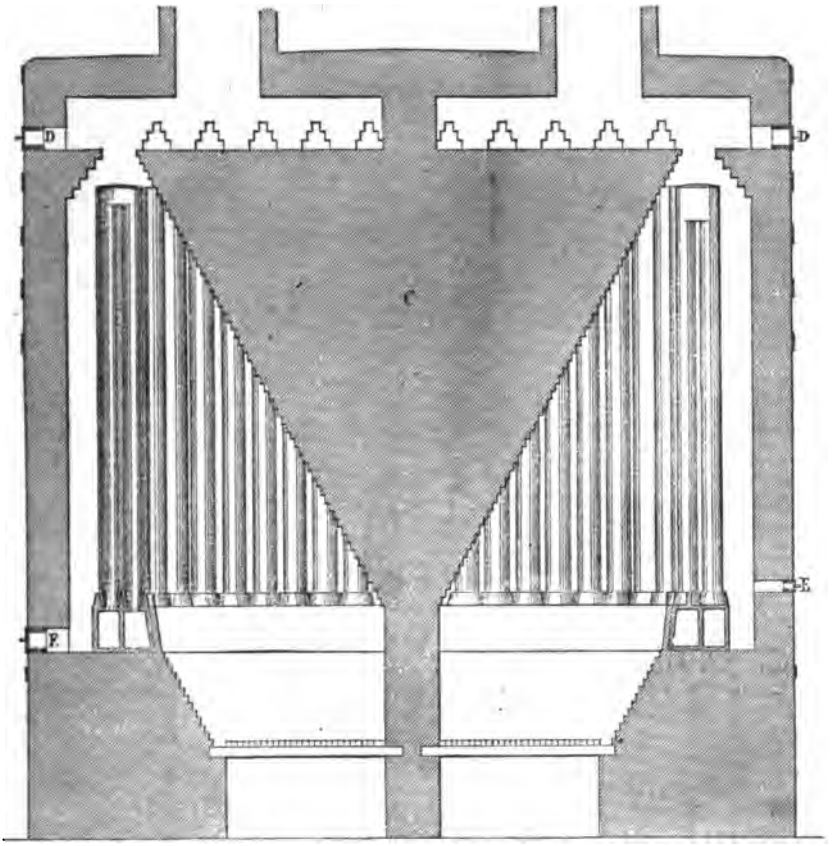
Round ovens were first introduced by Mr. Martin Baldwin at Bilston in

* See Greenwood's "Metallurgy," vol. i. figs. 26, 27, 28. See also "Engineering," Nov. 22, 1878, p. 410.

1851, the first round oven being shown in Fig. 315. The object of this construction was to insure the possession of a main of such a form that its expansion or contraction should not tend to disturb the sockets of the upright pipes, while these upright pipes should have in their form provision against fracture or burning, and also against any expansion which might strain the socket joints.

Another important object in designing this oven was to provide a form of casing which combined a good fire-grate area with compactness, the minimum amount of surface for radiation, and the greatest amount of reverberation or reflection of the radiant heat to the pipes. In durability and freedom from fracture of pipes and joints, the round oven was most

FIG. 318.

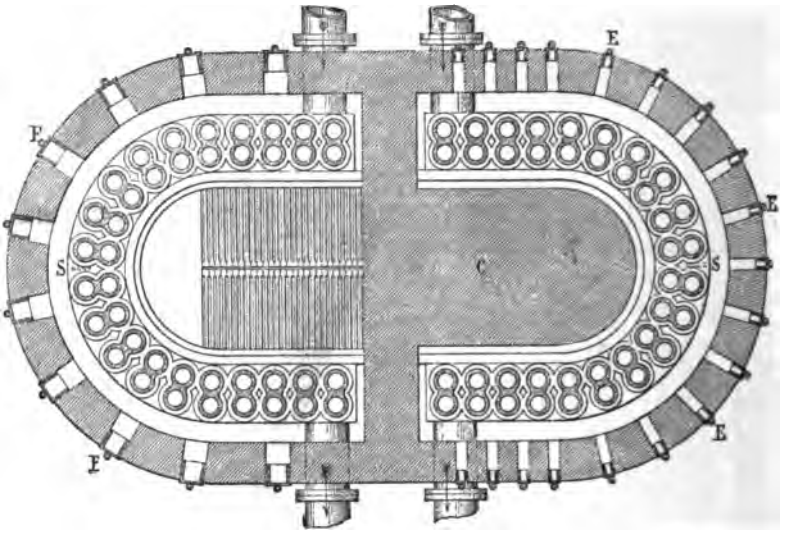


successful, the pipes and joints standing the stress of work without repair for several years. When the improvements in internal arrangement shown in Figs. 316 and 317 were added, the heating capacity of the oven was increased by one-third and the consumption of fuel was smaller. The advantages of the core consisted in increasing the reverberatory surface and in providing a reservoir of heat which corrected any irregularity in the temperature of firing. The vacant space in the centre of the tubes was thus profitably filled, and the hot gases were forced into more intimate contact with the pipes. The alterations in the flues at the top and in the division of the fire-grates below were also beneficial, so that, with a fire-

grate area of 38 square feet, and an area of direct heating surface in the pipes of 850 square feet, or 280 square feet per tuyere for three tuyeres, this oven was capable of heating the blast for three tuyeres to a temperature of 800° F.

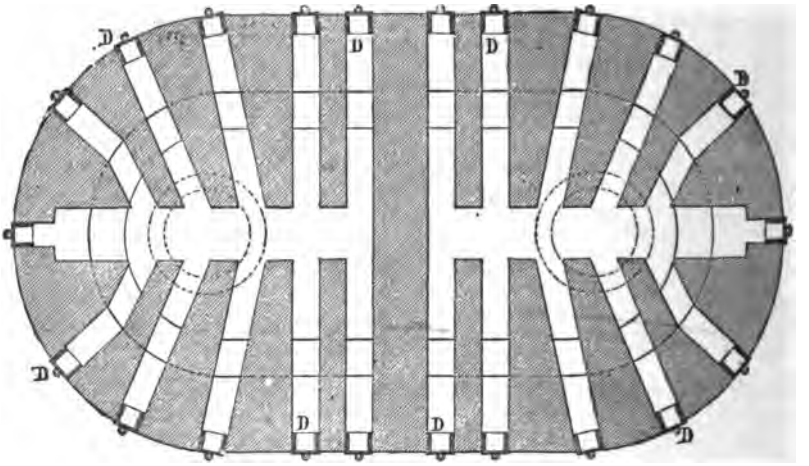
A later improvement in this direction is shown in Figs. 318-320,

FIG. 319.



the object of arranging the mains in the horse-shoe form, as shown in the sectional plan, Fig. 319, having been primarily to obtain more heating sur-

FIG. 320.



face than one round oven afforded without the expense of erecting two of them. Fig. 320 shows a plan of the top flues of this oven.

Some ovens erected on this plan, having 54 square feet of fire-grate area and 1,500 square feet of direct heating surface in the pipes, were said to be capable of supplying blast heated to 800° F. for ten tuyeres. This arrangement also provided means for cleaning the flues both above at D D and below

at F F, and the spaces between the pipes by doors at E E, without interfering with the working of the ovens.

With the introduction of improved forms it became possible to reduce the thickness of cast iron used in the heating pipes from 2½ inches in some early ovens to 1 inch, thus not only saving metal in construction, but increasing also their efficiency in transmitting heat to the blast, the rate of transmission being inversely as the thickness of the metal.

The use of a simple pyrometer, such as Gauntlett's, which was frequently used, enabled a constant heating effect to be produced without waste of fuel, and, as the result, considerable saving in fuel was realized in those ovens fired with solid fuel.

In early examples, 8 or 10 cwts. of slack coal per ton of iron made were required to heat the blast to 320° F., whilst later practice with improved ovens shows blast heated to 800° F. with 4¼ to 5 cwts. of slack per ton of iron.

There has thus been considerable advance made on the primitive arrangements introduced by Neilson for heating the blast in ironworks.

Some cast-iron pipe stoves heated by coal fires have been worked to a recent date in connection with open-topped blast furnaces,* but the plan of closing the tops of blast furnaces and using the waste gas as fuel having become almost universal, of course modifications in the arrangement of iron pipe stoves became necessary to suit the altered mode of firing. Moreover, higher temperatures of blast have come to be more in demand as the impression has prevailed that economy of working is to be obtained in this direction, and in result the temperatures originally introduced by Neilson have been left far behind—although Neilson has left on record† his belief in the value of higher temperatures than he was able to obtain.

There are iron pipe blast stoves in use, such as those of Mr. Gjers and others, which are fired by gas‡ and used to heat the blast to temperatures of 1,000° to 1,200° F., some ironmasters holding that they are quite equal to that work, and that further economy is not reached by employing higher temperatures. There are, however, others who maintain that there is no limit to the economy attainable by the use of higher blast temperatures, except that which is fixed by the combustion temperature of the waste gases, and, we may add, that of the durability of the material of which the stove is constructed.

Cowper's Stove.—With temperatures of 1,000° to 1,200° F. the limit of safety with cast-iron pipe stoves seems to have been reached, but stoves constructed of fire-brick have been introduced, and these greatly extend the range of temperatures at command.

An unsuccessful attempt was made in this direction by Siemens,§ but to Mr. E. A. Cowper belongs the honour of first introducing this important improvement in blast stoves. Mr. Cowper, who described his original design in a paper read before the Institution of Mechanical Engineers in 1860,‖ and communicated his later improvements to the Iron and Steel Institute,¶ adopted the principle of the so-called "regenerators" of the Siemens furnace, placing them inside air-tight wrought-iron casings lined with fire-brick. This construction of the "Cowper stove" introduced a new era in blast-furnace practice, rendering it possible to heat the blast to about double the temperature that was usual at that time. The stove is first heated up for about three hours by the combustion of gas within it, and then, the gas being turned off, cold blast is introduced, which,

* Percy's "Metallurgy," vol. Iron and Steel, pp. 399–418; "Popular Encyclopædia," art. Iron.

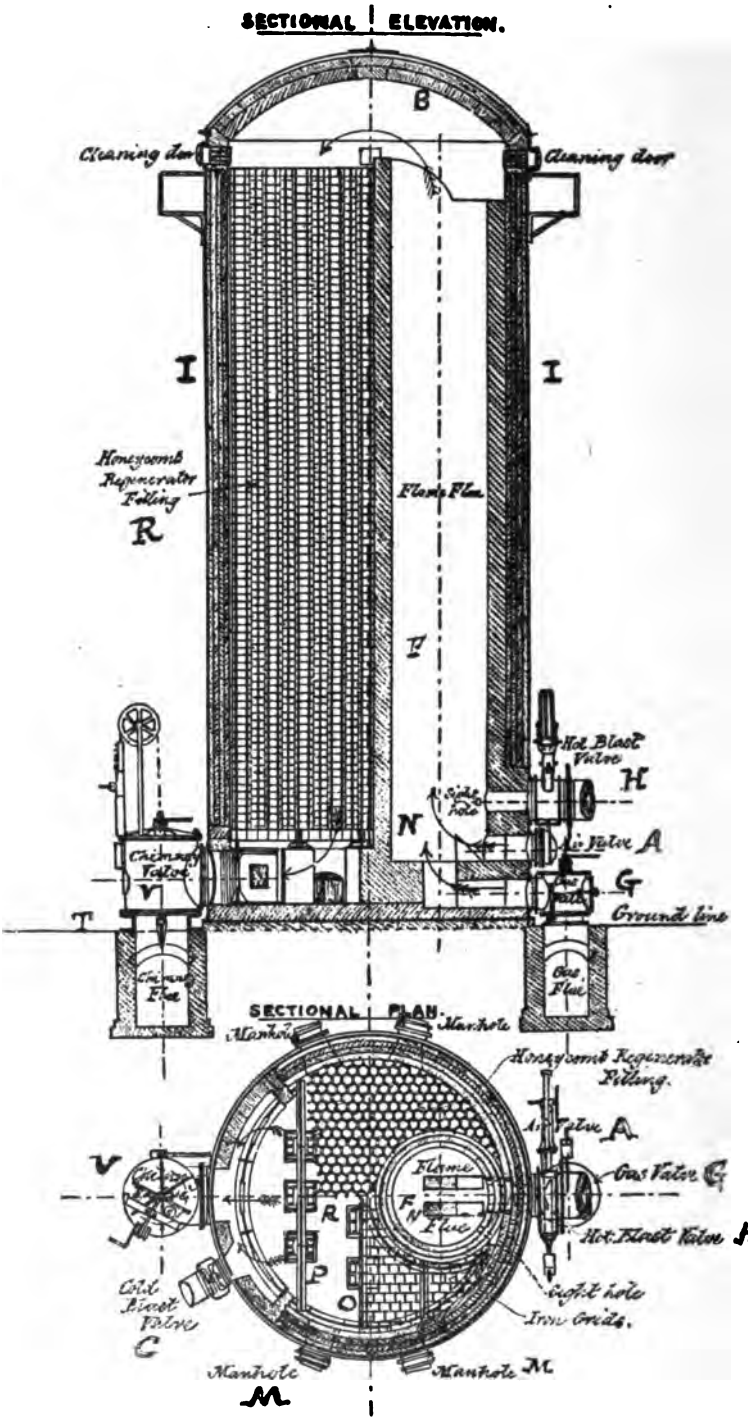
† "Proc. Inst. Mech. Eng.," vol. 1859. p. 68; vol. 1860, pp. 64, 66, 67.

‡ See "Engineering," Nov. 22, 1878, p. 410, &c.

§ See Dr. Percy, "Metallurgy," vol. Iron and Steel, p. 428.

‖ "Proceedings," vol. 1860, pp. 54–73, plates 8–14. ¶ "Journal," vol. ii. 1883, p. 576.

FIG. 321.


SECTIONAL ELEVATION.
B
Cleaning door
Cleaning door
I
I
Honeycomb Regenerator Filling
R
Flame Flue
F
Hot Blast Valve
H
Side hole
N
Air Valve A
Chimney Valve
V
Gas Valve G
Ground line
T
Chimney Flue
Gas Flue
SECTIONAL PLAN
Manhole
Manhole
Honeycomb Regenerator Filling.
Air Valve A
V
Flame
Gas Valve G
R
F
Flue
Hot Blast Valve H
P
O
Cold Blast Valve
C
Light hole
Iron Grids.
Manhole
Manhole
M
M

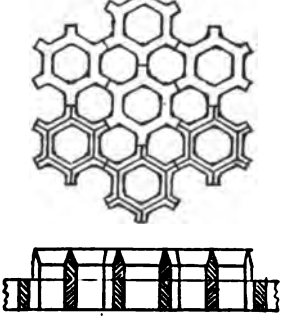
passing through the regenerator, takes up heat from the very surfaces that had previously absorbed it. The stoves are worked in pairs, so that as one is heating the blast, the other is being heated up.

The heating of the regenerator is effected by admitting blast-furnace gas through a valve at the bottom of a large flame flue, and air to mix with the gas by another valve. The gas being ignited, a large flame is formed, which passes up the flue and then descends once through the regenerator, composed of bricks in the form of a honeycomb, thus heating it most at the top. So perfect is the absorption of heat that the products of combustion, as they pass away through several openings to the chimney valve and thence to the chimney, are at a very low temperature; in fact, only about high enough to keep up the draught. When the heat has penetrated downwards nearly to the bottom of the regenerator after it has been in action for several hours, the valves just named are closed and the cold- and hot-blast valves are opened so that the blast may pass in at the bottom of the regenerator and, after traversing it upwards, pass from the top down the flame flue to the hot-blast valve.

It must not be understood that the whole mass of brickwork or "filling" inside the iron casing is heated up or cooled down to the same point. Were this done in heating up, the products of combustion or hot gases used for heating would pass away at the chimney flue end at the temperature to which the brick surfaces had been raised, and thus much heat would be lost. The upper portion of the filling is always hot and the lower part always cool, and "as the hot end approaches the temperature of the fire whilst the cold end is at the temperature of the chimney flue, so the temperature of either end varies but little even after several hours' heating; the heat, however, works farther in at the hot end, and there is less length of cold part at the cold end. The regular scale or gradation of temperature of the great bulk of the regenerator is simply shifted lower down in the mass of brickwork, there being a greater length of hot part then left at the upper end." When the blast is admitted, "precisely the opposite result takes place, in the gradual shifting upwards of the scale of temperature in the regenerator, until, by long-continued action of the cold blast in taking up heat from each course of bricks in succession, there is only a short length of thoroughly heated part left at the top, and a greater length of cooled part left at the bottom of the regenerator when it is time to change again."

The action of this apparatus thus seems to come as near to perfection as is possible with mechanical appliances, the hot gases being cooled to from 150° to 250° F. before they escape to the chimney, whilst the blast is heated up to nearly 1,500° F.

FIG. 322.



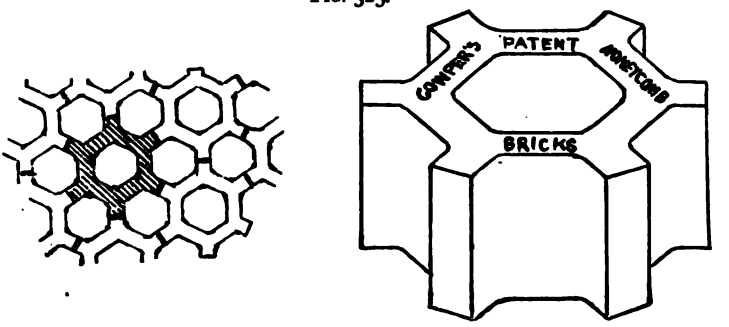
The Cowper stoves have been improved since their first introduction in 1860, but the last improvements—viz., the honeycomb bricks, and the branched passages to chimney valve—now used by Mr. Cowper are said to have surpassed anything that has hitherto been done.

In Fig. 321, I is the iron casing of the stove, B is the brick lining; R is the regenerator, a portion of the honeycomb filling—Fig. 322—being omitted in the plan in order to show the grids, O, and girders, P, on which they rest; H is the hot-blast valve, C is the cold-blast valve, A is the air valve, G is the gas valve, V is the chimney valve, F is the flame flue, N is the gas-burner, M are man-holes for access to the bottom of the stoves for taking out dust brought down by the firing of a gun or by the action of a brush thrust up from

below, and T is the throttle valve for suddenly discharging the air from the stove and blowing out dust.

The bricks forming the regenerator filling of "honeycomb" form are shown in Figs. 322, 323. The short spurs on the angles of each brick cause it to form other passages besides its own central one, and they impart stiffness

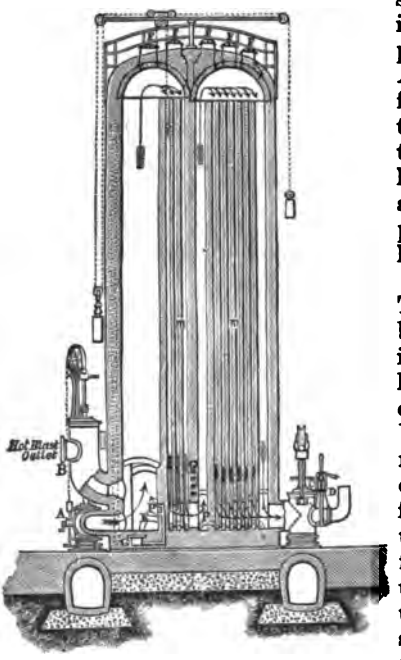
FIG. 323.



and strength to the brick. In consequence of the strength of this form, the bricks can be made only 2 inches thick, which, of course, permits of more even heating up than would be possible with thick masses, and is of advantage in other ways. The hexagonal form also has the advantage of preventing hanging of the dust. It is found that dust does to some extent hang in passages having square corners.

About four hundred Cowper stoves have been erected and put to work in various parts of the world, and they are said to make 15 to 20 per cent. more iron from the same plant than could be produced with cast-iron pipe stoves. As a consequence, that proportion of fuel per ton of iron made is saved, and this is a strong incentive to the adoption of such appliances, ironmasters of late years having found it necessary to adopt the most economical methods of producing iron, on account of the very low prices prevailing.

FIG. 324.



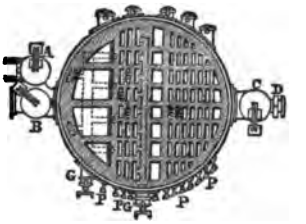
Whitwell's Stove.—The late Mr. Thomas Whitwell introduced a fire-brick stove, subsequent to Mr. Cowper's invention, which was worked under licence from Mr. Cowper during the currency of his first patent. The Whitwell stove has, however, been modified in form, and the principal differences between it in its present form and the Cowper stove consist in the arrangement of the fire-bricks forming the heating surfaces, and in the manner in which the combustion of the furnace gases is effected within the stove. In the Whitwell arrangement the heating surfaces consist of a number of narrow vertical flat walls or flues, shown at *m* in Figs. 324 and 325. In the Cowper stove the combustion of the furnace gases is effected in one

large flame flue or combustion chamber, whilst in Whitwell's arrangement the air required for the combustion of the gases is admitted at several points, and the combustion is thus completed only after the gases have partially traversed the stove.

The Whitwell stoves are from 60 to 70 feet in height, and from 20 to 22 feet in diameter. They consist of a vertical cylindrical casing of wrought-iron plates rivetted together, within which is built a lining of fire-bricks, but between this lining and the outer shell is left a space of about 1 inch, which is filled up with granulated slag.

Within the cylindrical chamber are built a series of narrow vertical chambers, *m m* (see Figs. 324 and 325), the different rows of which communicate with each other either at the top or at the bottom. Attached to the outside of the casing are cast-iron valves for regulating respectively the supply of gas, air, and blast to the stove, and for connecting the stove with the chimney.

FIG. 325.



The casing, &c., of the valves for admitting the blast-furnace gases to the stove and connecting the stove with the hot-blast main are usually made hollow, and are cooled by the circulation of water through them. Near to the bottom of the stoves are *eye pieces*, P P, arranged round the circumference, and through these a view of the interior is obtained so as to judge of its temperature and requirements. In the roof of the stove are apertures, F F, closed by covers during the regular working, but movable for the introduction of long scrapers for cleaning the dust. &c., from the several flues; also at E E, near the bottom, are arranged six openings for cleaning out the dust, &c., collected from the flues into the bottom of the stove, and which openings are closed by movable doors as required.

The gases from the blast furnaces enter the stove by the valve A, whilst, at the same time, air enters through the air-courses, G, sufficient in quantity, however, only for the partial combustion of the gases. The heated gases then ascend through the vertical combustion chambers to the top of the stove (as shown by the course of the arrows), where the gases distribute themselves over the tops of the flues and descend by one or more chambers towards the bottom of the stove. Here more air is admitted, and the combustion of the gases is completed as they re-ascend in the stove through another wide combustion chamber. The products of combustion finally descend through the other narrow flues or chambers to the chimney valve, from which they escape to the atmosphere at a temperature of from 300° to 400° F. (149° to 204° C.)

When the fire-brick chambers of the stove have been thus sufficiently heated, the gas valve, A, the chimney valve, C, and also the air valve, are each closed, whilst the cold-blast valve, D, and the hot-blast valve, B, which were previously closed, are thereupon opened. The current of blast thus enters the stove at its coldest point, D, near the chimney valve, and passes through the several passages towards the hotter parts of the stove, exactly in the reverse direction to that pursued by the gases in heating up the stove. In this manner the blast, by passing over the heated fire-brick, becomes heated before it passes out at B, to the hot-blast main to a temperature of 1,300° or 1,400° F. (704° to 738° C.), whilst higher temperatures are attained according as the reversal of the valves required for heating up the stoves and for passing the blast through the same is effected at intervals more or less frequent.

This arrangement of a second combustion chamber suggests the idea that the carbonic acid produced by the combustion in the first instance,

might prevent thorough combustion in the second chamber, and, as the primary combustion is purposely partial, the full heat of combustion of the furnace gas would not be obtained. Mr. William Whitwell, however, states that such a difficulty has not been experienced in working. "The second combustion chamber," he says, "enables us to burn off what unconsumed carbonic oxide remains in the gas, while the products of the first combustion chamber give their heat to the walls also, and in no degree interfere with the combustion. We have 800 to 900 stoves in all parts of the world, and the most successful practice, both in America and in England, is with Whitwell stoves."

Massicks and Crooke's Stove.*—Massicks and Crooke have designed the stove shown in Fig. 326. It consists of a cylindrical wrought-iron casing, with a conical top, which has a circular man-hole in the apex. This form of top obviates the difficulty and expense of having girders and cleaning doors. The internal brickwork arrangement is a series of segmental passages, commencing at the centre of the stove, where it is hottest, and terminating at the periphery, where it is coldest, thereby preventing radiation and consequent loss of heat, and affording greater protection to the iron casing. The gases to heat the stove, and the blast to be heated by the stove, are alternately passed through the segmental passages in opposite directions, and by this arrangement the largest amount of efficient and durable heating surface is obtained.

The difficulty of economical and thorough cleaning of fire-brick stoves has always been, apart from cost, a most serious defect, and it is claimed for this invention that by means of it this difficulty is overcome. Cleaning doors at the top and removal of brickwork are dispensed with by an arrangement of iron pipes, 2 inches in diameter, which are built into the brickwork of the top of the stove directly over each segmental passage. Through these pipes a chain or rod is passed to the bottom of the stove, and through the cleaning door or doors a scraper is attached thereto, which fits exactly each segmental passage. This scraper is caused to ascend and descend by a simple working rotary crane on the top of the stove, and in this way all the gas-dust adhering to the internal brickwork of the stove is entirely removed in a short time.

The gas and hot-blast valves have water or air passing through them. The chimney valve does not require cooling, as the temperature of the escaping gases is reduced to about 300° F., and a simple form of mushroom valve is designed for this purpose.

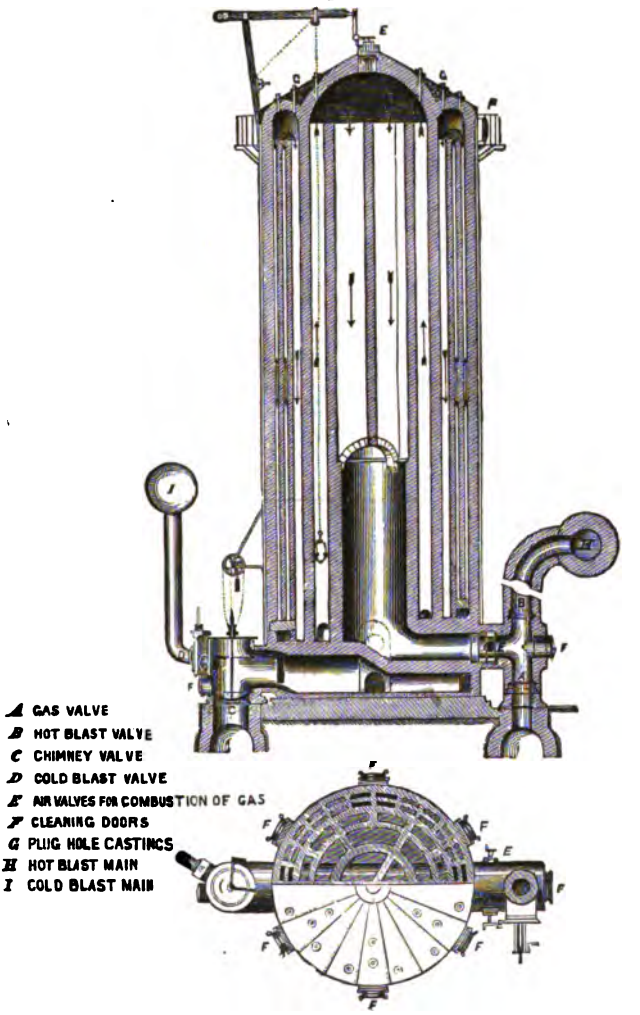
The advantages which are claimed for this stove are—comparatively small cost and simplicity of construction; an effectual, rapid, and cheap mode of cleaning; great structural strength, combined with a large amount of permanent heating surface. The main feature in this stove is the central heat. The passages are so arranged that as the hot gases approach the outer casing they become cooled down, until finally they are passed from the outermost passage under the centre of the stove to the chimney valve. The object of passing them towards the outside and then under the stove is to preserve both the iron casing and the bottom of the stove from too intense a heat. At each change from gas to blast the cold air first enters under the bottom of the stove, thence into the outermost passages, and thence inwards, gradually increasing in temperature by coming in contact with the hot brickwork, until finally it arrives in the central chamber, where it receives its final heat, and is thence passed direct into the tuyeres. This arrangement enables a light iron casing to be used, protected by only one course of brickwork. Five years' experience has tested the value of this design, and during that time it is said that not a single plate has been in-

* "Jour. Iron and Steel Inst.," vol. ii. 1882, p. 602.

jured by over-heating, although the central portion of the stove has been maintained at a red heat, never having been allowed to cool down except once in three or four months for cleaning purposes.

The diagram Fig. 327 (p. 470) gives a graphic representation of the consumption of coke per ton of iron made with blast heated to various degrees of temperature. The diagram was prepared by Messrs. Massicks and Crooke from data obtained in practical work with furnaces working at the

Fig. 326.


A GAS VALVE
B HOT BLAST VALVE
C CHIMNEY VALVE
D COLD BLAST VALVE
E AIR VALVES FOR COMBUSTION OF GAS
F CLEANING DOORS
G PLUG HOLE CASTINGS
H HOT BLAST MAIN
I COLD BLAST MAIN

Askam and Monzell Iron Co.'s works, and also at the Cumberland Iron Mining and Smelting Co.'s works.

Messrs. Massicks and Crooke remark that, after long experience, it has been found that 1,300° F. is the most economical temperature for work with modern blast-furnace plant, producing 100 to 120 tons of high free carbon pig-iron (Nos. 1, 2, and 3 Bessemer) per day of twenty-four hours. A higher temperature cannot be maintained so regularly at a uniform

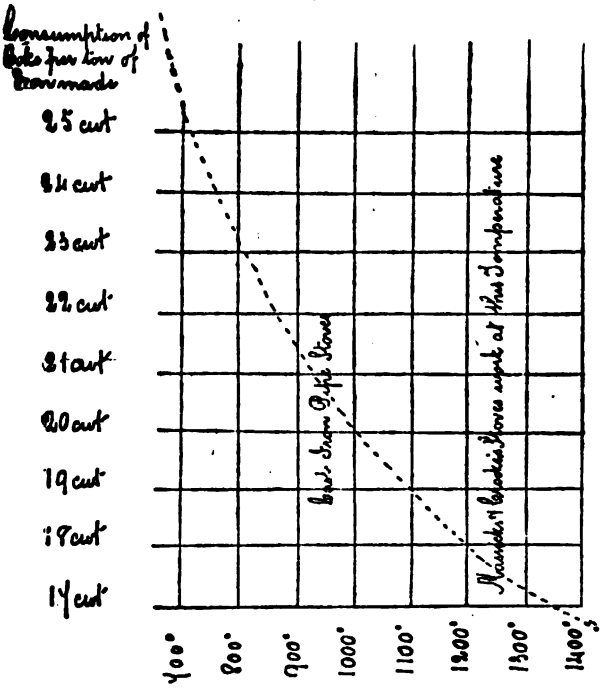
point, and in the working of a blast furnace this is of very great importance.

When it is considered that, in order to produce this yield of iron from one furnace, about 700 tons of air has to be passed through each pair of stoves in twenty-four hours, and raised from 60° to 1,300° F., some idea may be formed of the magnitude of the work. The result, however, makes it possible for the ironmaster to live, where a few years ago this would have been impossible with present prices of pig-iron.

One or two other modifications of the fire-brick stove have been introduced subsequent to those mentioned, such as Ford's, Harvey's, and some in America and Germany, but they need not be described in detail.

The table on p. 471, which was drawn up by Herr Lürmann,* gives some interesting comparative information regarding several of the best hot-

FIG. 327.



blast stoves in use. The data have been, where necessary, modified on the assumption that the blast which had to be heated was that required for one blast furnace of a daily consumption of 120 tons of coke, equivalent to 450 cubic metres of blast per minute.†

Principles of Hot Blast.—The scientific principles which govern the use of hot blast have been demonstrated by Sir I. Lowthian Bell, who has reduced to accurate figures the relative efficiency of the heat of a unit of carbon when burnt outside the furnace (the heat being conveyed into the hearth by the blast) and of a unit burnt in the interior of the furnace. In Neilson's day, circumstances, especially in Scotland, made it appear as if the former was many times more efficacious than the latter, but better understanding of the actions taking place in the blast furnace has supplied the

* *Stahl und Eisen*, 1883, p. 27.

† Refer to "Jour. Iron and Steel Inst.," vol. ii. 1883, p. 699, for an article "On Computing the Surface required in Hot-blast Stoves."

	No. of Stoves required for One Blast Furnace of 100 Tons Production.	No. of Stoves required for Actual Use.	Heating Surface (Square Metres)					Cost in Marks or Shillings				
			of Each Stove.	of Stoves built for Each Blast Furnace.	of Stoves in Actual Use for Each Blast Furnace.	per Cubic Metre of Blast built.	per Cubic Metre of Blast in Actual Use.	of Each Stove.	per Blast Furnace.	per Square Metre of Heating Surface.	per Square Metre of Heating Surface in Use.	of Heating Surface built per Cubic Metre of Blast.
A. *Brick Stoves.*												
1. Whitwell's old system, cost in Germany	4.0	3	900.0	3,600	2,700	8.00	6.00	50,000	200,000	55.50	74.00	444
2. Do. do. do.	4.0	3	800.0	3,200	2,400	7.10	5.33	62,500	250,000	78.00	104.00	554
3. Do. recent installation, cost in Germany . . .	2.5	2	2,400.0	6,000	4,800	13.30	10.66	26,000	65,000	11.00	13 50	145
4. Do. do. cost in England	2.5	2	2,400.0	6,000	4,800	13.30	10.66	32,000	80,000	13.30	16.70	178
5. Cowper, in Germany . . .	3.0	2	4,800.0	14,400	9,600	32.00	21.33	40,000	120,000	8.33	12.60	267
6. Do. do.	3.0	2	4,800.0	14,400	9,600	32.00	21.33	48,000	144,000	10.00	15.00	320
7. Massicks & Crooke, cost in England .	3.5	3	1,440.0	5,000	4,320	11.10	9.60	15,100	52,850	10.50	12.20	117
8. Do. do. do. Germany	3.5	3	1,440.0	5,000	4,320	11.10	9.60	20,000	70,000	14.00	16.20	155
9. Harvey, cost in Germany . . .	2.5	2	4,600.0	11,500	9,200	25.50	20.40	33,000	82,500	7.20	8.97	184
B. *Pipe Stoves.*												
10. Gjers, cost in Germany . . .	5.0	5	136.0	680	680	1.51	1.51	14,000	70,000	102.90	102.90	155
11. Do. do. . . .	6.0	6	163.7	982	982	2.18	2.18	16,666	100,000	101.80	101.80	222

explanation of the seeming anomaly; for this, we are indebted to none so much as to Sir I. Lowthian Bell. He has shown that the keys to this subject are the capacity of the furnace and the susceptibility of the ore which it contains to reduction by carbonic oxide, or, as otherwise expressed, the equalization of the rates of reduction and of fusion, whilst the index to the chemical changes taking place in the blast furnace is found in the relative proportions of carbonic oxide and carbonic acid which the escaping gases contain.

The effect of increased capacity of furnace on the combustion within will be understood if we consider the nature of the action which takes place.

"If a piece of carbon, such as charcoal," remarks Sir Lowthian Bell,* "is heated to redness, and continues to burn, surrounded on all sides by air, it will do so without any visible flame. Each molecule of the combustible is converted at once into carbonic acid with the development of the largest amount of heat its combustion can give rise to—viz., about 8,000 centigrade units of heat per unit of carbon.

"If, on the other hand, several pieces of carbon are placed in contact with each other, and the air required for their combustion is made to pass upwards through the mass, a blue flame will appear at the top. This is due to the formation of carbonic oxide from some or all of the carbonic acid on its passage through the heated carbon, this carbonic oxide burning in contact with the air.

"In all low fires, such as the Catalan hearth and the refinery, the real nature of the combustion varies with circumstances, such as the depth of the fire and the temperature of the fuel, whether it be charcoal or coke. As a rule, we may take it that near the tuyeres of these shallow furnaces there is a certain amount of carbonic acid present, only part of which is reduced higher up to the state of carbonic oxide. In this way a portion of the carbon arrives at the surface of the fire in the form of carbonic acid, and there it mingles with that resulting from the combustion of any carbonic oxide which may reach this point as such.

"It thus happens that, in such arrangements as those last mentioned, the whole of the carbon, in the one way or the other, passes up the chimney as carbonic acid, having evolved by its oxidation the greatest amount of heat it is capable of affording. It is clear, however, that, when the object of such a fire as the Catalan or the refinery is the imparting of heat to some body immersed in the fuel, it cannot be otherwise than an exceedingly wasteful operation. That portion of the carbon which is burnt below the surface of the fuel passes too rapidly upwards to have time to impart more than a mere fraction of its heat to the matter exposed to its influence. On the other hand, such combustion as takes place on the surface of the mass is scarcely in contact with the body to be heated, and exercises little or no useful effect.

"Let us now compare the nature of the combustion as it is effected in the blast furnace, and the application of the resulting heat, with that just described. For this purpose we will suppose that the fuel is burnt in a furnace having a height of 80 feet. The result of several analyses† satisfied me that almost all traces of carbonic acid disappear within a foot or two of the level of the tuyeres; we may therefore infer that, in the absence of any subsequent change, the whole of the carbon burnt at the hearth would be given off at the throat as carbonic oxide. Imagine such a furnace filled with coke, along with a neutral substance, such as slag, not liable to any chemical change. Fire is communicated below, and the blast applied. Combustion rapidly sets in, and the gases, as they arrive at the top, soon become sensibly

* "Principles of the Manufacture of Iron and Steel," p. 62.
† "Chemical Phenomena of Iron Smelting," pp. 8 and 9.

warmer. Their temperature will continue to rise until, at the rate at which the furnace is driven, the refrigerating influence of the cold materials as they enter establishes a position of heat equilibrium, and the mean temperature of the gases will then remain stationary. It is easy to note the time when this occurs, and to observe the exact quantity of coke which has been burnt between this epoch and that at which the blast was laid on. The number of heat units evolved by burning this weight of coke is easily computed, and along with it the weight of gases which has been generated by its combustion. The mean temperature of these gases having been noted, we can ascertain with tolerable nicety the quantity of heat they are carrying away with them. The difference between the two sets of figures represents the quantity of heat intercepted by the incoming materials."

The amount of this difference was ascertained by Sir I. L. Bell on two occasions* when "blowing in" a furnace, and found to be such that, for every calorie originally evolved in the hearth by the direct combustion of the fuel, 2.33 calories were brought back thither by the materials descending from the upper region of the furnaces, and he gives the following statement of the heat development in the hearth per unit of carbon consumed therein :—

	Heat Calories.
1 unit of carbon burnt at the hearth to carbonic oxide gives . . .	2,400
Heat imparted to the gases by the combustion of preceding units of carbon, which heat, being intercepted by the descending materials, is returned to the hearth in the ratio given above—viz., 2.33 to 1—and gives .	5,592
Together . .	7,992

"Practically, therefore," adds Sir L. Bell, "the combustion of a unit of carbon burnt to carbonic oxide in a blast furnace of 80 feet gives nearly as good an effective result, although it evolves only 2,400 calories, as the same quantity of carbon burnt to carbonic acid in a low fire, although, in the latter case, 8,000 calories per unit of carbon are generated. There is, however, this marked difference between the two examples, that whereas the 7,992 heat units referred to in the case of the blast furnace are almost all usefully employed, a very large proportion of the 8,000, evolved in the low hearth escapes into the air unutilized. In the low fire, as experience tells us, there is an enormous waste of heat, which is indeed visible in the flame and incandescence at the surface of the fuel. On the other hand, in a blast furnace of 80 feet the materials are, it is true, red hot for more than 50 feet above the hearth, but the upper surface of the materials, instead of being red hot, exhibits little or no signs of incandescence, proving a comparative freedom from waste due to this cause."

The temperature of the escaping gases, and therefore the amount of waste of fuel from imperfect utilization of its heat, is regulated to a great extent by the size and capacity of the furnace. Not wholly, however, because the reduction of oxide of iron by means of carbonic oxide is a chemical action, which has been proved in the blast furnace to be of a heat-producing character, so that either the quality of the ferric oxide or the period of contact between it and the carbonic oxide may decide the temperature and quality of the escaping gas, and, consequently, the quantity of fuel used in producing iron.

Sir I. L. Bell takes† the case of "two furnaces of equal capacity, each fed with a different kind of ironstone and driven at exactly the same speed. If both varieties of ore lost their oxygen at the same rate, reduction in each case would be performed in the same way, so far as regards its being effected by carbon or carbonic oxide. If, on the other hand, one of the ores were

* "Chemical Phenomena of Iron Smelting," p. 293.
† "Principles of Manufacture of Iron and Steel," p. 82.

much less susceptible than the other to the influence of the deoxidizing agency at work in the higher zone of the furnace, then, in any given time, a larger proportion of such ore would descend unreduced into the region where reduction is carried on by solid carbon, and would therefore be accompanied by a waste of fuel."

In "illustration of the loss arising from a diminution in the quantity of carbon escaping as carbonic acid in relation to the iron produced," Sir Lowthian Bell assumes "the case of an easily reducible ore, the heat requirements of which may be estimated at 96,000 calories per 20 units of pig-iron produced.

"If in such a case we have 6 units of carbon per 20 units of iron in the gases as carbonic acid, we should have—

			Calories.
These	6 units of carbon	× 8,000 calories	= 48,000
Leaving	20 „	to escape as carbonic oxide burnt with air at 0° C. × 2,400	= 48,000
Total	26 „	making together the	96,000

Included in these 96,000 calories we may assume 12,000 to be carried off in the escaping gases.

"Let us now suppose that another variety of ore, resembling the previous one in everything but in readiness with which it parts with its oxygen, to be treated in a furnace of the same capacity as that used in the former case. As a consequence, it is assumed that by the time it is half reduced a zone of the furnace is reached of such a temperature that carbonic acid is immediately decomposed by heated carbon. Granting that we have now only 3 units of carbon per 20 units of pig-iron escaping as carbonic acid, the account will stand thus:—

			Calories.
The	3 units of carbon as carbonic acid	× 8,000	= 24,000
Leaving	30 „ „	oxide, burnt with air at 0° C. to provide the remainder × 2,400 . .	= 72,000
Total	33 „ „	making	96,000

The difference, 33 − 26 = 7 units of carbon, is not, however, the full measure of the loss: because, not only is the volume of escaping gas much larger than in the former instance, but it is also carried off less perfectly cooled than it was when smelting the more reducible ore. It might therefore easily happen that 1½ to 2 units of fuel might disappear in this way, bringing up the difference to nearly half a ton of coke per ton of iron, and all owing to there being a diminution of 3 units of carbon as carbonic acid in the gases."

In answer to the question, in what way can the heating of the blast produce an effect resembling in character that consequent on an enlargement of the furnace, Sir I. L. Bell says: "Let us assume that in a furnace of the olden type—say 50 feet high, and containing 6,000 cubic feet, blown with air at 32° F. (0° C.)—35 cwts. of carbon per ton of iron was burnt at the tuyeres, while in another, driven with air at such a temperature that 15,000 heat units per ton of iron entered the furnace with the blast, only 25 cwts. of carbon was consumed in the hearth.

"The heat development in the cold-blast furnace at the tuyeres when carbonic oxide only is generated would be 35 × 2,400 = 84,000 units.

	Calories.
With hot air the heat development also at the tuyeres is 25 × 2,400	= 60,000
Add heat in the blast	15,000
Total . .	75,000 units.

But the volume of gases conveying through the materials the 84,000 calories produced by the cold air is 40 per cent. larger than that which is the vehicle of the 75,000 units produced by the hot air.

"It is therefore certain that the retarded rate at which the gases must pass upwards in the latter instance will enable them to impart a larger quantity of their sensible heat to the cold materials, and will afford the carbonic oxide a correspondingly longer time to act on the ore than can be the case with the larger volume."

Practical illustration of the correctness of these deductions was afforded by the results obtained at some furnaces belonging to Earl Granville, where "prolonged exposure of the solids to the gases was obtained, not by diminishing the volume of the latter, but by increasing the height of the furnace to 71 feet, when precisely the same economy of fuel was obtained with cold blast in the enlarged furnaces, as if heated air had been used in those of the olden type, say of 6,000 cubic feet capacity."

One ton of metal was made at these furnaces under the following conditions:—

	Cwts. of Coke.
Cold blast in a small furnace, of say 50 feet, with about	40¼
Hot blast in a small furnace } with about . .	28¼
Cold blast in an enlarged furnace }	

Sir I. L. Bell concludes that hot air and increased capacity of furnace mean one and the same thing, and quotes another result to confirm it. "In the hot-blast furnace of 6,000 cubic feet capacity the air may be considered as having been heated to about 1,000° F. (538° C.), but when the temperature was raised by means of fire-brick stoves to about 1,400° F. (760° C.), and this was applied to a furnace of 7,500 cubic feet, the consumption of fuel was the same as that in a furnace of about 11,500 cubic feet blown with air at 1,000° F. (538° C.)."

Elsewhere* Sir I. L. Bell has remarked that "independently of any increase of temperature in the upper portion of the furnace, the use of hot blast introduces a change in the relation between the solid and gaseous contents, which will have the effect of accelerating the tendency towards an equalization of the temperature of the two. By this action, the ore is more speedily heated, and the gases, in consequence, are more quickly saturated with oxygen. This arises from the longer retention in the furnace of the carbonic oxide evolved by the combustion of a given weight of coke," when it is burnt with hot air, as compared with its combustion with cold air. Thus, if a furnace of 6,000 cubic feet capacity receives 14,400 cwt. heat units by means of hot blast, "this is equal to the heat from 6 cwts. of carbon burnt to carbonic oxide, which carbon can therefore be at once withdrawn from the fuel introduced with the charges. This quantity of carbon represents 38.8 cwts. of gases, which is equivalent to about 10 per cent. in volume of those flowing up through the contents of a furnace using originally 60 cwts. of coke per ton of iron. During the time, therefore, each cwt. of carbon is engaged in fusing the iron and slag in the hearth, while in the act of being converted into carbonic oxide, the carbonic oxide thus formed is retained by the diminution of its volume one-tenth longer in the furnace, and by so much its contact with the materials the gases have to heat and to reduce is prolonged. This effects a further saving of fuel, and in consequence a further reduction in the volume of gas is accompanied again by an addition to the time of retention of this gas in the furnace. This is continued until the fuel is diminished in quantity, as far as a furnace of the proper dimensions is capable of producing a ton of iron, which is not reached until the gases in bulk are a trifle above one-half of what they were when the blast

* "Min. Proc. Inst. C.E.," vol. xxxiv. part ii.

consisted of cold air instead of with the supposed addition of 14,400 heat units." It is clear that under such circumstances the reducing gases will be twice as long in contact with the ore they have to reduce and with the materials they have to heat as when cold blast is employed, and the instances previously quoted show that it is time rather than any mysterious quality of hot blast which effects a change in the saving of fuel in a blast furnace.

In fact, supposing a furnace having "sufficient capacity to permit the two functions of fusion and reduction to proceed in point of time in unison with each other, instead of one heat unit in the blast doing the work of three or four previously evolved by the fuel, each unit of heat thrown in with the air does no more duty than one unit produced by the combustion of coke inside the furnace."

There are, however, practical advantages in the use of heated blast which must, to some extent, outweigh strictly calorific considerations. Thus, as Sir I. L. Bell points out, "conveying heat into the furnace by means of the blast enables the smelter to pour in a supply where it is most required, without waiting for any change in the burden of coke and ironstone which come down into the hearth." Again, the air may be heated by fuel of greatly inferior value to that which is used in the furnace itself. "The fuel used in heating the blast is the gas which escapes from the furnace, which in many, indeed in most, cases would be wasted, but may at the best be valued as small coal, which, in the North of England, can be had for threepence per cwt. If, then, by burning 2 cwts. of coal worth sixpence, or, still better, by burning furnace-gas costing nothing, 3 cwts. of coke, worth, it may be, two shillings, could be saved, a great gain would arise from such a change."

In addition to this, the use of hot blast must have the advantage over even an equivalent increase of capacity beyond a certain point, because, when the height of the furnace is carried beyond the limit, soon fixed by experience as the most suitable for working conditions, the weight of the burden interferes with the proper condition of the materials, compressing and even crushing the portions most easily friable, and offers resistance to the passage of the gases and blast through a lofty column of solid minerals. Sir I. L. Bell also remarks that, "strictly speaking, some small allowance must be made in favour of superheated air, owing to the diminished volume and somewhat reduced temperature of the escaping gases, consequent on the reduced quantity of carbon burnt by the blast, and the smaller quantity of carbonic acid per 20 units of iron which is generated at the top of the furnace."

The facts that, by increasing the temperature of the blast, the quantity of solid carbon charged into the furnace is reduced, thus diminishing the quantity of useful gases produced, and that the zone of high temperature is carried to a greater height in the furnace, thus causing interference with the reducing operations, show, however, that the conditions of the smelting process themselves impose limits on the elevation of blast temperature, even in spite of economy of fuel.

Sir I. L. Bell shows that theoretically the reduction of iron ore and carbon deposition arising from dissociation of carbonic oxide limit the carbon escaping as carbonic acid from a Cleveland furnace to 6.58 units per 20 units of pig-iron. Practically, however, more or less of this carbonic acid is wanting. A very common quantity would be 5.58 units, which means a deficiency of 5,600 calories where 86,000 calories in all are required. Stating the two cases, we have :—

	Units.		Units.
Carbon as carbonic acid .	6.58	. . . .	5.58
By oxidation of carbon, calories	80,528	86,000	74,928	86,000
In hot blast ,,	5,472		11,072	

Sir I. L. Bell says "this statement is intended to prove that, if the carbon fails to perform its full theoretical duty, the deficiency in the instance cited is made up by additional heat of the blast; but it is equally true that the more heat contained in the blast, the larger must be the quantity of carbonic acid which disappears from the gases per 20 units of iron made, because the heat so conveyed into the furnace is intended to displace, and does displace, so much carbon introduced as coke; and, as the two oxides of carbon have to be maintained in certain relations to each other, it is obvious that we cannot, when the two are found in these relations, alter the quantity of the one without at the same time producing a rateable effect on the other."

In order to show the temperature of blast necessary for its substitution for coke as successively smaller portions of carbon are burnt for heat production, where the carbon as carbonic acid is to that as carbonic oxide in the resulting gases as 1 to 2, and where 86,000 calories are required per 20 units of iron made, Sir I. L. Bell gives the following figures:—

Carbon burnt by Blast.	Weight of Blast.	Burnt to		Heat produced by		Total from Carbon.	Blast to provide	Total Heat.	Temp. of Blast.	
		CO_2.	CO.	CO_2.	CO.				Deg. C.	Deg. F.
18	104.3	6.00	12.00	48,000	28,800	=76,800	9,200	=86,000	372	701
17	98.5	5.67	11.33	45,360	27,192	=72,552	13,448	=86,000	576	1,069
16	92.7	5.33	10.67	42,640	25,608	=68,248	17,752	=86,000	808	1,486
15	86.9	5.00	10.00	40,000	24,000	=64,000	22,000	=86,000	1,068	1,954

Corrected for CO_2 to CO as 1 to 2.22, the figures become:—

18	74,504	11,496	=86,000	465	869
17	70,368	15,632	=86,000	669	1,236
16	66,232	19,768	=86,000	900	1,652
15	62,040	23.960	=86,000	1,163	2,152

It is not likely, however, that the highest temperature, namely, 2,152° F., will be attained in practice, from the fact that it is almost impossible to find a material capable of withstanding such a temperature in regular work, and consequently Sir I. L. Bell adopts 1,600° to 1,700° F. as a practicable point to be attained, and gives the equivalent consumption in coke (using about 12 units of limestone for smelting Cleveland ironstone) as follows:—

Units of carbon per 20 units of iron burnt with blast at 1,652° F.	16.00
Carbon burnt by carbonic acid in limestone	1.44
Carbon in iron	0.60
	18.04
Add for impurities to 18.04 carbon to bring it to coke, say 7½ per cent.	1.35
	19.39

He remarks on this, "It must not be supposed that this weight of coke is unchangeable, as it is susceptible of some trifling modification arising from differences in the richness of the ore or of the quantity of flux required. With this qualification, 19½ cwts. of coke may, in my opinion, be accepted as the possible limit with which a ton of Cleveland foundry iron will be produced using air at a temperature of nearly 1,700° F. If so we have a gain of 1 cwt. of fuel or thereabouts, as compared with the case when the blast is heated only to 1,000° F."

H. Schellhammer* has investigated in a very careful manner the influence of pressure of blast on the working of blast furnaces, and more especially the relation of the pressure and quantity of the blast to the consumption of fuel and the composition and temperature of the gases.

* *Oest. Zeit. für B. u. H.*. No. 35, *et seq.*; "Jour. Iron and Steel Inst.," vol. ii. 1882, p. 745.

His results and calculations are embodied in several tables and diagrams of considerable interest, but his conclusions are not beyond question.

Generally it appears that increase of pressure—involving increase of quantity of blast per minute—is accompanied by a smaller consumption of fuel and a higher temperature of the gas, which means a higher temperature throughout the furnace and a larger zone of indirect reduction. With a low pressure, the blast does not penetrate into the centre of the hearth, but rises along the sides of the furnace. As a consequence, a column of imperfectly reduced ore mixed with charcoal comes down in the centre, and has to be reduced directly by solid carbon. As only a part of the ore is acted on by a very great body of gas, a large quantity of carbonic acid must remain inactive and escape without being further oxidized. With increased pressure, the blast penetrates deeper into the crucible, the column of imperfectly prepared ore will be less and the quantity of carbon used for direct reduction is diminished. The absorption of heat which accompanies direct reduction will also be less: therefore the temperature at the tuyeres and in consequence the temperature of the whole furnace will rise. The gas, although up to a pressure of 190 millimetres it is less in quantity and richer in carbonic acid, acts on the ore within a larger space and at a more favourable temperature, and is so enabled still to perform its duty.

Herr Schellhammer lays particular stress on the reaction by which carbonic acid (exclusive of what is introduced as carbonate in the ore and as a gaseous constituent of the charcoal) is formed, whether by direct reduction of ore in the lower parts or indirectly by oxidation of carbonic oxide in the upper parts of the furnace. He calls these two quantities D and I respectively, and expresses their proportion by $\frac{D}{I}$ in his tables of results, but although the most economical consumption of fuel ought theoretically to be expected when $\frac{D}{I} = 0$, viz., when no direct reduction takes place, in fact the minimum of fuel in his results is found when $\frac{D}{I} = .200$.

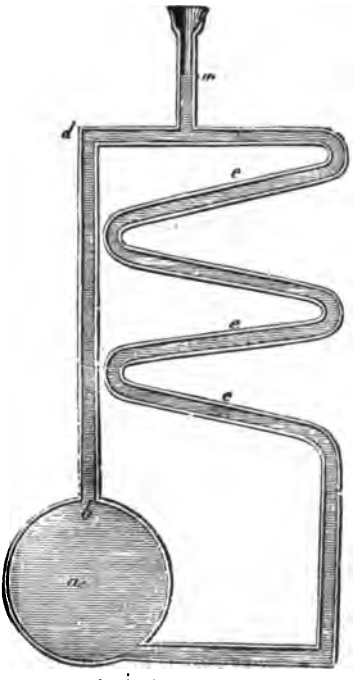
HEATING BY WATER AND STEAM.

Water and steam are frequently employed as carriers of heat, for which purpose they are particularly well adapted, in consequence of the high specific heat of the former and the large quantity of latent heat contained in steam. According to De la Roche and Bérard, the quantities of heat contained in equal weights of water and air at the same temperature are in the ratio of 374.6 : 100; or the heat which is liberated when water cools down 100° C. is sufficient to raise the temperature of 3.74 times as much air to the same amount. Regnault's results correspond with the factor 4.21, giving even a larger heating value. We have here, therefore, an analogous case to that of clay; the heat destined for a given quantity of air can be retained or accumulated in a much less quantity of water; and a still greater effect is produced when water, in the form of vapour, is made the purveyor of the heat. In passing into the state of vapour, water absorbs 5.36 times as much heat as is required to heat it from 0° to 100°, and this quantity of heat producing no increase of temperature in the steam, it cannot be recognized by the thermometer, but again becomes sensible when the vapour is condensed. Consequently, 1 lb. of vapour at 100° (212° F.) will, in condensing to form boiling water, give off sufficient heat to raise the temperature of 5.36 lbs. of water, or $4.21 \times 5.36 = 22.6$ lbs. of air to 100° (212° F.).

When warm water is employed, it must necessarily be renewed in pro-

portion to the amount of heat required, and, to avoid the trouble of constantly changing the water, a certain portion is caused to circulate in such a manner as to keep up a continuous ascending current of warm, and a descending current of cold, water. Fig. 328 shows the principle of the circulation. The heat applied to the bottom of the vessel *a* is first communicated to the lower layers of water, which, becoming expanded and specifically lighter, rise to the higher parts of the vessel; they ascend to *b*, from thence into the tube *c*, and lastly to *d*. In proportion as these portions rise, however, the cold water descends in *e*, and this circulation is kept up as long as any difference of temperature exists in the different parts of the apparatus, a condition which is constantly maintained by the cooling of the water in its passage. It is obvious that *a* may be an open vessel, into which the ends of the tube dip like a siphon, but then much heat will be lost. The heat itself, in this arrangement, is the motive power for producing the circulation, which is so much the more rapid the fewer cooling and other obstacles are placed in the way of the ascending current.

Fig. 328.



In this country, where the system of heating by water was introduced by Perkins, closed coppers are used, which can be heated in the same manner as steam boilers; or the pipes themselves, without any boiler, are carried through a stove in numerous coils. The dimensions of the fire and the conducting pipe must be well proportioned to each other, so that the cooling takes place rapidly, and no steam is formed. To avoid all danger from explosion, which a sudden burst of steam might possibly occasion, safety-valves are introduced, and compensating pieces, to prevent the bursting of the metal tubes by sudden expansion and contraction. The latter danger is guarded against by connecting the ends of the pipes with a stuffing-box, instead of with screws, thus combining mobility with a water-tight connection. Tubes are also provided at the top of the conducting pipes, as at *m*, for the escape of the air, which is evolved on heating the water.

The quantity of water which is to be conveyed per minute from the apparatus to the space to be heated can be determined in the following manner. If *A* represents the number of cubic feet of air, at a temperature of $t°$ warmer than the external air, which have to be supplied per minute; and if 1 cubic foot of water is 770 times heavier than 1 cubic foot of air, then *A* cubic feet of air correspond with $\frac{A}{770}$ cubic feet of water by weight; but the heat which raised the temperature of *A* to $t°$ is only capable of raising the $\frac{1}{4}$th of this $\frac{A}{770}$, or, more correctly, $\frac{A}{4.21 \times 770}$, to the same temperature; in other words, $\frac{A}{4.21 \times 770}$ cubic feet of water in cooling $t°$ will raise exactly *A* cubic feet of air to the same temperature. But the water in the pipes has a temperature of nearly 100° C. (212° F.), and gives off

from 60° to 70° of this, or cools $(T-t')°$; therefore, as much less water will be required as $(T-t')°$ is higher than $t°$, namely:

$$\frac{A\,t°}{4.21 \times 770\,(T-t')°} = \frac{A\,t°}{3{,}241.7\,(T-t')°} = Q \text{ cubic feet} = Q\ 62.32 \text{ lbs.}$$

of water per minute. It is necessary to know the velocity with which water moves in pipes, in order to construct the conducting pipes of proper dimensions.* The determination of this is the same in principle as that of the draught in chimneys, the friction of the water being somewhat different from that of the air. The velocity, together with Q, gives the diameter of the pipes, and the latter the dimensions of the fire. The ascending pipe is straight, and surrounded by badly conducting substances, to prevent cooling; the descending pipe, on the contrary, is furnished with every facility for communicating heat to the air of the room. When the heat is to be communicated to a very extensive space, the water becomes too cold in the more remote rooms, and a separate set of pipes for each half of the building is desirable.

Steam heats much more effectively than water, and consequently less of it is required. As 24.6 cubic feet of air at 0° weigh 1 lb., then A cubic feet in the former equation will weigh $\frac{A}{24.6}$ lbs., and will be heated by the condensation of $\frac{A}{24.6 \times 4.21 \times 5.5}$ lbs. of steam of 100° C. (212° F.) in forming boiling water (of 100° C.), and consequently by $\frac{A\,t°}{24.6 \times 4\ 21 \times 5.36 \times 100} = Q$ lbs. of steam to $t°$ higher than the temperature of the external air. The pipes destined to carry the steam to the place of condensation are chosen of narrow bore (about 1.5 inch), and, to avoid all condensation during the transit, are surrounded with a thick covering of felt, woollen cloth, or other bad conductor of heat; the condensing pipes are of copper or cast iron, at least four times as wide, and must be so arranged that the air can escape when the steam is first admitted, or this would otherwise very much retard its dissemination. These pipes should be rough and not polished, and the copper tubes should be painted or stained so as to give them the appearance and the properties of cast iron. To allow for the expansion in length, the same plan may be adopted as in water-pipes, or simply a bent piece of flexible metal may be inserted into the course of the tube, which by bending to a greater or less degree, compensates for the expansion. It is found that different bodies condense steam in a very unequal manner, according to the nature of their surfaces and to their co-efficients of conductivity. Tredgold found the following quantities of steam condensed per hour by a square foot of surface of the different substances in the form of pipes exposed to a temperature of 59° F.:—

Tin-plate	0.185 lb.
Glass	0.333
New sheet-iron	0.340
Rusty sheet-iron	0.393

Clement further observed that, at a temperature of 15° C. (59° F.) in the surrounding air, 1 square foot of surface of horizontal cast-iron pipe would condense 0.234 lb. of vapour, of bright copper pipe 0.184 lb., and of blackened copper pipe 0.213 lb., which quantities are somewhat increased by a perpendicular position of the pipes.

Whatever form is given to the apparatus, ample means must be afforded for the removal of the condensed water, and a special set of pipes, conducting it back to the boiler, is generally employed for this purpose. Occasionally, a quantity of water is expressly left in the pipes after circulation has

* Refer to "Proc. Inst. C.E.," vol. xii. pp. 25–109; vol. xiii. pp. 64–120; vol. xiv., J. Leslie, "On the Flow of Water through Pipes;" vol. xviii. pp. 363–403; and art. Hydromechanics, "Encyclopædia Brit.," vol. xii.

ceased, that the accumulated heat (as in clay stoves) may be obtained. In order to prevent any sudden or unexpected powerful condensation drawing up the water from the boiler, there must be a valve, opening downwards somewhere about the spot where the vapour enters the system of pipes. There is a greater loss of heat, on account of the larger dimensions of the pipes, when air is made the medium of transmission, than when either water or steam is employed, while the latter are not so well calculated to assist ventilation. When water is employed as the heating medium, the apparatus is, on the whole, simpler, the temperature more easily regulated, and not so suddenly elevated as by the use of steam; the latter, however, will convey the heat to much greater distances, and can be employed to heat the upper floors of lofty buildings, where the pressure of columns of water would prove very inconvenient.

The diameters of the condensing pipes, when steam is used, must not be too large, or the air is expelled with difficulty; nor too small, or the friction will impede the passage of the steam, and diminish its tension. They may vary from 3 to 8 inches in diameter, and the best manner of supporting them is by iron rods fixed to the ceiling.

The Emission of Heat by Hot-water Pipes.—Some very interesting experiments and observations on the emission of heat by hot-water pipes are recorded by Mr. W. Anderson in Min. Proc. Inst. C.E., vol. xlviii. p. 257. He remarks that Prof. Balfour Stewart in his Elementary Treatise on Heat (articles 229–235 and 285–287) gives a clear explanation of the process of cooling by radiation and convection, in which he quotes Dulong and Petit's formula as modified by Hopkins, according to which the total amount of heat radiated per square foot per hour may be found by the expression—

$$m \times a^{\theta}(a^{t}-1),$$

and the heat carried off by convection in atmospheric air by the formula—

$$0.0372\left(\frac{p}{720}\right)^{0.45} \times t^{1.233},$$

in which

$a = 1.0077$
θ = temperature of the air surrounding the pipes
t = difference of temperature between the air and the pipes, both temperatures in degrees C.
p = height of barometer in millimetres
m = a co-efficient of radiation.

Mr. Anderson's experiments were undertaken for the purpose of determining the co-efficient m for the usual hot-water pipes employed in practice.

Reduced to British units and 30 inches height of the barometer, the formula becomes—

$$u = \text{total units emitted per square foot per hour by radiation and convection} = m \times 1.00427^{\theta}(1.00427^{t}-1) + 0.2853 \times t^{1.233},$$

$$\text{whence } m = \frac{u - 0.2853 \times t^{1.233}}{1.00427^{\theta}(1.00427^{t}-1)}.$$

"The method adopted for obtaining m was to raise a coil of iron pipes of known weight, and containing a known weight of water to a certain temperature, then allowing it to cool while observing the temperature at equal intervals of time.

"Thermometers were inserted into the pipes at the upper and lower ends of the coil, and precautions were taken to guard against accumulations of air in the pipes and other disturbing causes. The time of cooling and the fall of temperature being thus ascertained, the number of units of heat

emitted was easily calculated, and the value of m determined, not only for each experiment during the whole process of cooling, but for intervals of about one hour in each case. To make sure that no serious errors of observation had been committed, the fall of temperature was plotted in curves, in which the abscissæ represented the time, and the ordinates the temperature of the air as well as that of the pipes."

Mr. Anderson states, as a result observed in his experiments, that "a considerable error is committed by assuming, as is commonly done, that the mean temperature of a coil is the arithmetical mean of the extreme temperatures. For example, for a coil of 4-inch pipes the true mean temperature in cooling from 69°.5 down to 23°.7 is 40°.52, while the arithmetical mean is 46°.6. It is obvious, supposing hot water to be flowing through the coil so as to cool to the same extent during its passage, that the mean temperature would have to be ascertained by a curve in the same way."

The results of eight experiments are given in the following Table. The 2-inch coils forming the subject of the first five experiments were made of common galvanized pipes, connected together by galvanized wrought-iron elbows. The coils were not covered by a casing, and were placed in a boiler-house tolerably well protected from draughts.

Values of Co-efficient m of Radiation in the Formula

$$u = m \times 1.00427_\theta(1.00427 - 1) + 0.285 \times t^{1.333}$$

Derived from Experiment

Experiments.	1. Duration of Experiment.	2. Maximum Temperature of Coil.	3. Mean Temperature of Air.	4. Mean Temperature of Coil.	5. Mean Difference of Temperature between Coil and Air.	6. Fall of Temperature during Experiment.	7. Mean Value of Co-efficient of Radiation = m.	8. Units of Heat per sq. foot for 50° Difference, 60° Air Temperature calculated.
	Hours.	Degrees.	Degrees	Degrees.	Degrees.	Degrees.		
1. A single coil of 2-inch galvanized-iron pipes; heating surface, 25.949 square feet. Weight of iron in coil, 205 lbs; weight of water contained in coil, 53 lbs.	3.500	206.00	51.50	103.00	51.50	143.0	270.90	119.10
2. A single coil, same as No. 1, but with a vertical sheet of iron between the pipes	3.833	205.00	50.13	100.28	50.15	144.5	252.90	113.50
3. Single coil, same as No. 1, blackleaded	3.833	206.00	52.90	103.75	50.85	143.3	241.00	109.90
4. Single coil, same as No. 2, and blackleaded in addition	3.583	205.09	52.27	106.07	53.80	140.5	235 30	108.10
5. Single coil, same as No. 1, with a second similar coil placed next to it	3.833	202.00	52.62	103.66	51.04	138.0	231.80	107.20
6. A coil of 4-inch cast-iron pipes, 87 square feet surface. Weight of cast iron, 1,564 lbs.; weight of water contained, 265 lbs.	4.033	133.00	59.75	102.11	42.36	47.8	121.70	73.00
7. Coil of 2-inch cast-iron pipe in room of ironworks office, blackleaded, uncased; surface, 34.2 square feet. Weight—cast iron, 318 lbs.; water, 64 lbs.	3.000	130.50	61.50	98.50	37.00	53.2	123 03	73.44
8. Same as No. 7	4.000	133.50	61.40	95.80	34.45	61.7	108.80	69.00
9 and 10. Battery of 2-inch wrought-iron tubes, connecting two cast-iron steam chests, heated by 36 lbs. steam; 232 square feet of surface	1.000	282.00	58.71	282.00	223.30	—	272.30	
	1.000	282.50	59.50	282.50	223.00	—	262.90	

The effect of placing a piece of sheet-iron vertically between the two rows of pipes and of blackleading and brushing the pipes, was to reduce the rate of cooling. A second coil placed beside the first retarded its cooling only 10 per cent. The 2-inch cast-iron pipes were old, but the 4-inch and 2-inch wrought-iron pipes were new.

"An examination of the formula shows that radiation only is affected by the temperature of the atmosphere, and that the emission of heat is greater as the temperature of the air increases. Taking the case of the 4-inch cast-iron pipes, with $m = 122$, a constant difference of temperature, $t = 50°$, the total heat emitted per square foot per hour becomes $u = 29.13 \times 1.00427^{\theta} + 35.46$, and solving for θ, the temperature of the atmosphere ranging from 32° to 60°, the following result is obtained:—

Temperature of air, θ =	32°	39°	46°	53°	60°
Total heat units, u =	68.87	69.89	70.94	72.01	73.13

"The difference of emission between the extremes is only 4.26 units, or a little over 6 per cent. more at 60° than at 32°. As, for the purpose of warming buildings, the air in the rooms is generally taken to be at 60°, and as any small variation from that temperature will not affect the rate of cooling much, two curves may be calculated for 4-inch cast-iron and 2-inch wrought-iron pipes with the co-efficient of radiation 122 and 250 respectively (the mean of the several values of m), which will enable the total units of heat given out per square foot of surface per hour to be ascertained by inspection for any difference of temperature. Fig. 329 gives these curves.

"Suppose, for example, it is required to know how much heat will be given out by 4-inch pipes at 190° in a room, the temperature of which is 60°, the difference of temperature being 130°; look along the line of abscissæ for 130, and the ordinate then gives 232.7 units for 4-inch pipes and 356 units for 2-inch wrought-iron pipes per square foot per hour.

"The heating surface necessary to warm a given building depends on a variety of circumstances—on geographical position, whether the house stands high and exposed or low and sheltered, and whether the average winter temperature is high or low; on the thickness and material of walls; on the area and construction of windows, and so forth. Very little can be done by calculation; the area as well as disposition of the pipes must be a matter of judgment."

A Table showing what has been done in one or two buildings is given by Mr. Anderson, from which, he says, "it would appear that for ordinary dwelling-houses 1 square foot of surface is necessary to every 65 cubic feet of air to be heated, and in a greenhouse 1 square foot to every 24 cubic feet of air.

"When the water circulates through the pipes by virtue of the difference of temperature of the flow and return currents only, it is impossible to count upon a greater mean temperature of the pipes than from 160° to 180°, because above that temperature the water in the boiler begins to boil, and causes an overflow of the supply cistern and escape of steam at the air-pipes.

"When forced circulation is adopted—as, for example, at the Third Middlesex County Lunatic Asylum at Banstead, near Sutton, where the water is propelled by a centrifugal pump, and where it is under a pressure of about 70 feet—a much higher temperature can be attained. One of the advantages in heating by steam is the high temperature that can be obtained in the pipes, but the disadvantage is that it is difficult to moderate the temperature in warm weather."

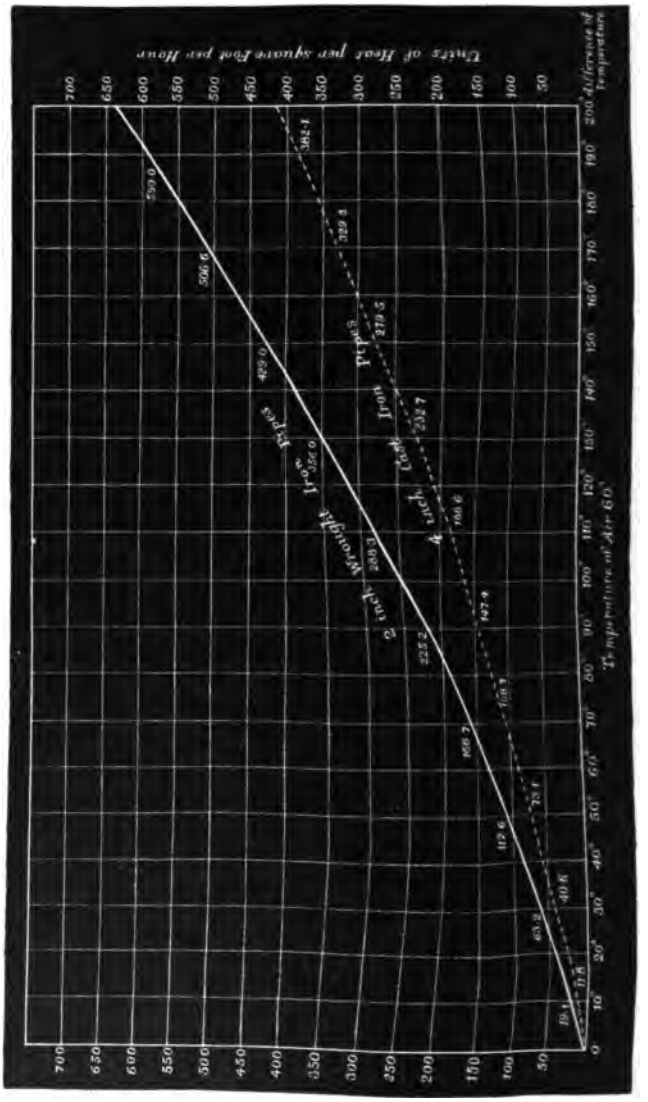
Mr. Anderson at one time thought that pipes heated by steam might possibly emit heat more quickly than those warmed by hot water. Some

experiments which were made in 1870 on a tubular steam heater, however, showed that the rate of emission was as nearly as possible the same as with tubes of the same size heated by water.

"The heater consisted of fifty-nine 2-inch wrought-iron tubes 6 feet 5 inches long connecting two cast-iron steam chests 7 feet long and 1 foot 3 inches wide.

"The heating surface of the tubes was 197 square feet and of the steam

FIG. 339.


Units of Heat per square Foot per Hour
Difference of Temperature
Temperature of Air 60°
Wrought Iron Pipes
Cast Iron Pipes
4 inch Wrought Iron Pipes
Smaller Pipes

chest 35 square feet, or 232 square feet in all. By means of diaphragms in the chests the steam was made to circulate through the pipes." Two experiments of an hour's duration each gave the weight of steam that could be condensed. The result was that 184½ and 180 lbs. of water were drawn off in the two experiments. From this it followed that 785.7 and 766.5

units of heat per square foot per hour must have been given off, and that the co-efficient of radiation must have been equal to 272.3 and 262.9, or nearly the same as that derived from the 2-inch wrought-iron water-pipes.

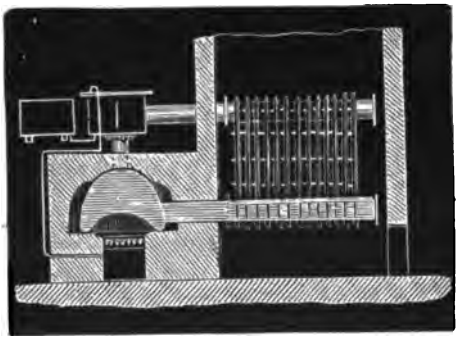
One of the best modes of employing steam is shown in Fig. 330. There is only one pipe through which the steam ascends from the boiler, and also only one extensive coil of pipe by which the condensed water returns. This arrangement is better than those in which the steam enters a number of pipes simultaneously, for it is difficult in the latter case to remove the air perfectly from all the pipes. A cock for allowing the air to escape must be introduced at the top of the pipe, but this is not shown in the drawing. When placed in the locality to be heated, the above apparatus becomes a steam-stove. If at a distance, and surrounded with a case, through the bottom of which air enters, the warmed current of air may be transmitted to a higher position. If the diameter of the pipes is small, the length must be increased in proportion to afford a sufficient heating-surface. The pipes may be of copper or iron; the latter are cheaper, and require no additional support.

Fig. 330.

It is always desirable to conduct the condensed water again to the boiler; heat is thus economized, and the incrustation of the boiler and pipes, which often proves a very serious inconvenience, is prevented.

The new Infirmary in Edinburgh is heated by means of a system of uncovered pipes and coils containing-low pressure steam, the radiation from the hot surfaces and also the transference of heat by contact and convection of air currents serving to warm the air of wards and passages, whilst the condensed steam is collected in return water pipes by which it is led back to the boiler-house and is there again utilized in the boilers.

Fig. 331.



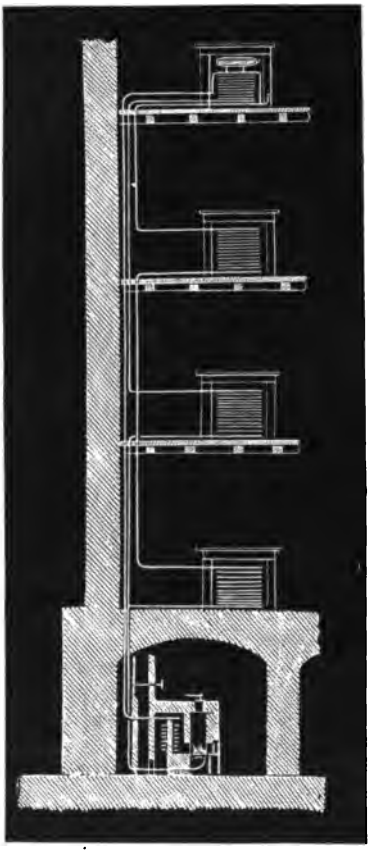
There are three steel cylindrical multitubular boilers of 5 feet 6 inches diameter, and 15 feet long, devoted to this heating system. These have the furnaces placed underneath, the hot gases returning through about 60 return tubes of 2½ or 3 inches diameter, whence they pass along flues running alongside the boilers and escape to the chimney. The boilers are worked at about 10 to 20 lbs. pressure per square inch, and the total area in steam pipes, coils and return water pipes throughout the infirmary buildings is about 17,000 square feet.

The average temperature of the water returned to the receiver at the boiler-house is usually about 140° to 150° F.

A similar system of heating was installed at St. Paul's Schools, West Kensington, London, in the year 1885.

Price's hot-water stove for heating air, which is used in many public establishments in this country, is shown in Fig. 331. The heating-surfaces are constructed of square cast-iron boxes, placed vertically, affording about 3 feet surface, and connected at two of the opposite angles with horizontal pipes. The joints are secured with collars of iron-wire gauze and red putty, which stand remarkably well. The boilers may be heated with a continuous supply of anthracite in the manner described below (*vide* Evaporation).

Fig. 332.



The hot-water system invented by Mr. Perkins, which is shown in Fig. 332, was introduced into the British Museum, is arranged on a different plan. The apparatus consists of a circuit of pipes of small diameter, surmounted by an hermetically closed expansion vessel; the lower portions of the circuit pass in several coils through a furnace, where the water becomes heated to a very high temperature.

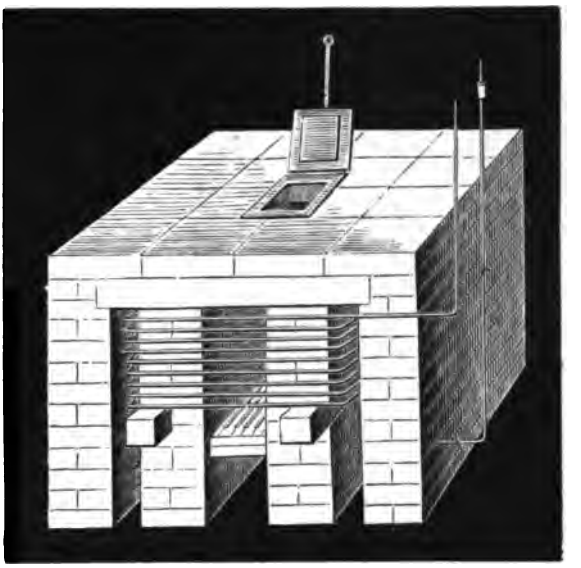
Fig. 333 represents the general arrangement of one of these coils. The water ascends by a single tube from the furnace, and descends in two tubes, each of which forms two helices at different elevations. The tubes are about an inch in diameter, very thick, and capable of withstanding a pressure of 3,000 atmospheres. A force-pump is employed in filling the tube with water, which completely expels the air and at the same time affords an opportunity of testing the strength of the apparatus up to a pressure of 200 atmospheres. The tubes are screwed together in such a manner that the somewhat tapering end of the one enters the flat metallic surface of the other.

It has been found by experience that the portion of the circuit heated by the furnace should not be much less than $\frac{1}{3}$th of the entire length. In Fig. 333 the coil of pipe is quadrangular, and so arranged in the furnace that the flame heats the one-half in ascending, and the other in descending before escaping to the chimney.

Figs. 333 and 334 represent the furnaces as employed at the British Museum. Fig. 333 is a perspective view, with the front wall removed, and Fig. 334 a horizontal section. The fire is supplied with fuel from above; the smoke and hot gases pass round the entire circuit of pipe before escaping to the chimney. The temperature of the pipes in the highest part of the circuit is generally from 300° to 400° F., and in the lowest part of the descending column it does not exceed 140° to 160° F., which temperatures correspond to pressures of from 4 to 15 atmospheres. In the furnace,

however, the pipes are heated to low redness, and if the water acquired that temperature, which is calculated at 932° F., the pressure would amount to 857 atmospheres.

Fig. 333.

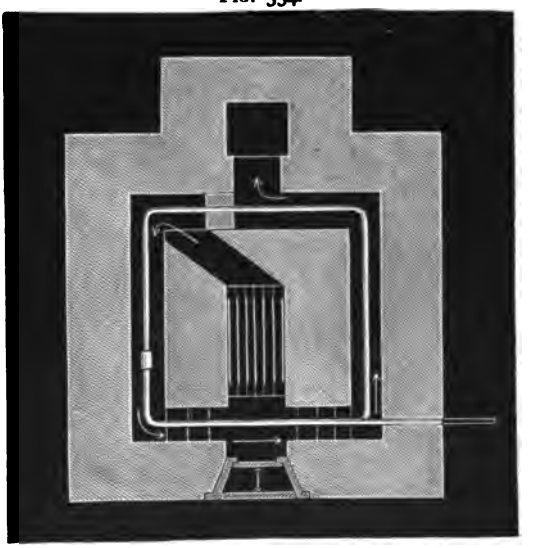


On account of the high temperatures coincident with the high pressures employed, this system has been thought to be dangerous as a probable source of fire. A Report* drawn up by experts appointed by the Manchester Assurance Co. to investigate this matter substantiates that opinion.

Notwithstanding every precaution, there is a constant loss of a small quantity of water, even when no perceptible leakage can be discovered; and in extensive coils it is necessary to add about a pint of water every eight or ten days.

The total extent of circuit is seldom allowed to exceed 400 to 500 feet, and 2 feet in length is considered sufficient heating surface for 100 cubic feet of space.

Fig. 334.



A very admirable system of heating and ventilating by hot water was adopted in many of the public buildings of France, on the recommendation of committees consisting of the most eminent scientific men of the day, and was carried out by very able engineers. As one illustration of the system, which is modified according to circumstances, we select from the numerous plans described by Péclet† in his *Nouveaux documents relatifs au chauffage et à la ventilation des établissements publics*, that which was adopted at the Mazas prison. This building was constructed for the solitary confinement of prisoners, whose health and comfort, as far as they are

* See "On Practical Ventilation and Warming," by J. Constantine.
† See also "Practical Treatise on Heat," by T. Box (London: Spon).

dependent on warmth and pure air, were certainly considered with the greatest attention, and in a manner worthy of imitation by governmental boards in other countries.

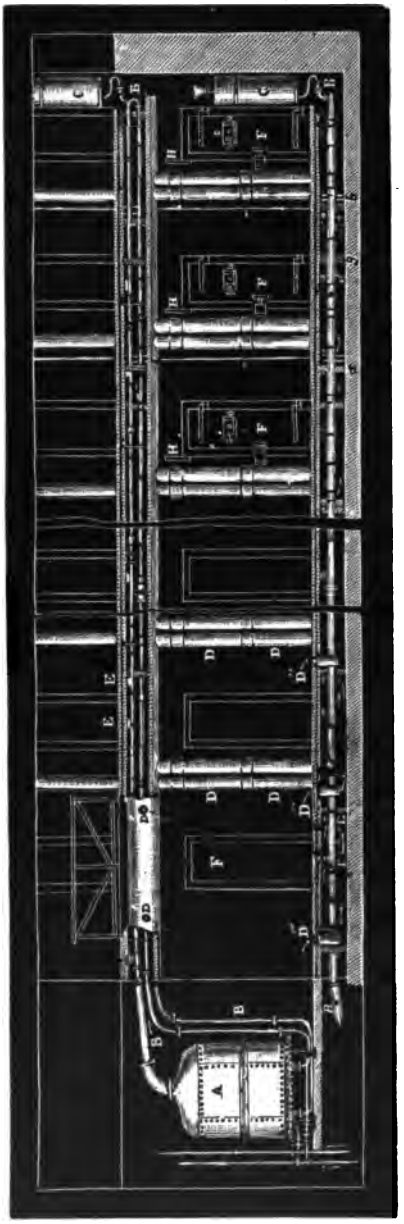
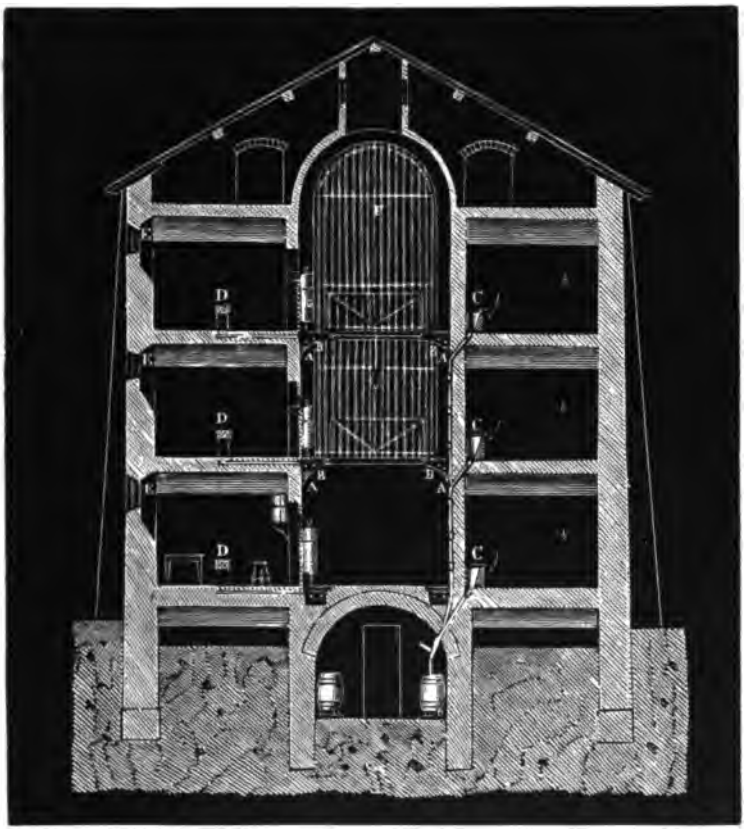


Fig. 335.

The prison consists of six long stacks of building, each of which is two stories high, radiating from a common centre. The middle of each of these is occupied by a long corridor, extending from the ground floor to the roof, and terminated by a large window. On either side is a range of cells, the capacity of each being about 700 cubic feet. Upon the system of M. Grouvelle, to whom the heating and ventilation of the building were entrusted, the air supplied to the cells was heated by contact with pipes containing hot water, which are in connection with reservoirs on each floor, where the water was heated by a coil of steam pipes supplied from generators in the basement of the central building. Ventilation was produced by a vast chimney about 40 square feet in section, and nearly 100 feet high, which is also situated in the centre of the edifice. The whole of the air from the cells was drawn by the action of this chimney in a downward direction through a vertical pipe in each cell, which, being in connection with a night-stool, served at the same time for removing excrementitious matters; the pipes from the several cells terminated in an underground vault, whence the vitiated air was drawn off by the chimney draught, while the solid and liquid excrements were collected in barrels, to be removed at fixed intervals. A balcony extends along each corridor at the height of the first and second stories, on to which the cell doors open. Channels were carried below these balconies in which two sets of cast-iron pipes conveyed currents of hot water in opposite directions, by which means a uniformity of temperature was established throughout the entire circuit. On the ground floor, this channel was below the floor in front of the cell doors. The channel was intersected by partitions corresponding with the walls of each cell, and the air from the corridor was admitted to the spaces between these partitions by gratings, and thence, after coming into contact with a considerable surface of pipe, was admitted through several apertures to the interior of the cells.

Fig. 335 is a vertical section of one of the buildings, on a plane parallel to the axis, and in part through the middle of one of the side balconies. *A* is the large wrought-iron reservoir, in which the water is heated by a coil of steam pipes supplied from the underground generators; *C C* are vessels in connection with the systems of pipes to afford space for the expansion of the water. *D D* the pipes for conveying the fæcal matters and vitiated air from the cells. *D' D'* apertures for admitting the air of the corridor to the channels containing the hot-water pipes. *D'' D''* apertures for the air to enter the channels situated below the ground floor. *E E* apertures connecting the channel with the interior of the cells. On leaving the reservoir, the hot water traverses the single pipe, shown in Fig. 336; but on arriving under the first cell, a branch pipe conducts a portion to the opposite side of

Fig. 336.



the corridor, so that hot water is flowing simultaneously through pipes on both sides, the cooled water returning in the same manner to the bottom of the reservoir.

Fig. 336 shows a vertical section of one of the cellular buildings at right angles to the axis. Each cell is rather more than 12 feet long, about 6 feet 6 inches wide, and nearly 10 feet high; each contains a gas-burner and a night-stool *C*, the descending-pipe from which carries the vitiated air of the apartment into the vault below, which is in communication at the one extremity with the ventilating chimney, and closed by a double door at the

other, which is only occasionally used for removing the barrels. The air escapes between the lid and the seat of the stool from the cells, and through the short appendages on the pipes into the vault; the longer extremity of the pipe dips into the close barrel; the air aperture can be stopped by a cap and some hay. *A B* are the hot-water pipes extending the whole length of the building below the galleries, and enclosed in a plastered channel; the air of the corridor has access to this, and passes warmed into the cells through the apertures *D*, which can be closed by plates of cast-iron. *E* windows of the cells; these are now never opened, in consequence of the great irregularity in the ventilation, which resulted from the effects of wind and sun. *F* is the grated window at the end of the corridor. *G* expansion-vessels.

According to the report of a committee on the whole system of heating and ventilation, the chimney is capable of drawing 1,059,300 cubic feet of air per hour, which, as there are 1,200 cells altogether, is equivalent to 882.7 cubic feet of air per cell per hour, or more than double the quantity required; very careful experiments having proved that 353 cubic feet per hour was amply sufficient to remove all noxious effluvia and establish a thorough current down the ventilating pipes. By means of registers in the subterranean air-vaults, the ventilation can be rendered uniform in all the six ranges of building. The quantity of air actually supplied averaged, during several months, between 529 and 882 cubic feet for each cell in the hour. A temperature of 55° to 61° F. was maintained during winter in all the inhabited parts of the building, and the apparatus was capable of affording more heat if required, only four of the six steam generators having been employed. For the seven months during which artificial heat was required, the mean temperature of Paris being about 43° F. and assuming the interior of the building to have a mean temperature of 57° F., the consumption of coal for the production of the difference in temperature of 14° F. was, on an average, $5\frac{1}{4}$ cwts. a day for each of the six stacks of building, and 2 cwts. for the general offices of the prison. The total consumption was therefore $5\frac{1}{4} \times 6 + 2 = 33\frac{1}{2}$ cwts. a day.

For producing the ventilation, the mean consumption of fuel was in summer 8 cwts., and in winter 7 cwts. a day; but for obtaining a ventilation of 1,059,300 cubic feet per hour, the consumption of coal in winter was 44 lbs., and in summer 55 lbs. per hour.

In the year 1852, a committee, appointed by the managers of the Infirmary at Newcastle-upon-Tyne, inspected the principal hospitals, both in London and the provinces, with a view to ascertain the best practical method of warming and ventilating such institutions. So universal was the support given to the open fire for heat, and the window for admitting air, that the committee, after mature consideration, agreed to adopt this plan as being more healthy, cheerful, and under better control. The execution was entrusted to Mr. Dobson, architect, who gave the following drawings and description of the plans carried out by him, which were eminently successful.

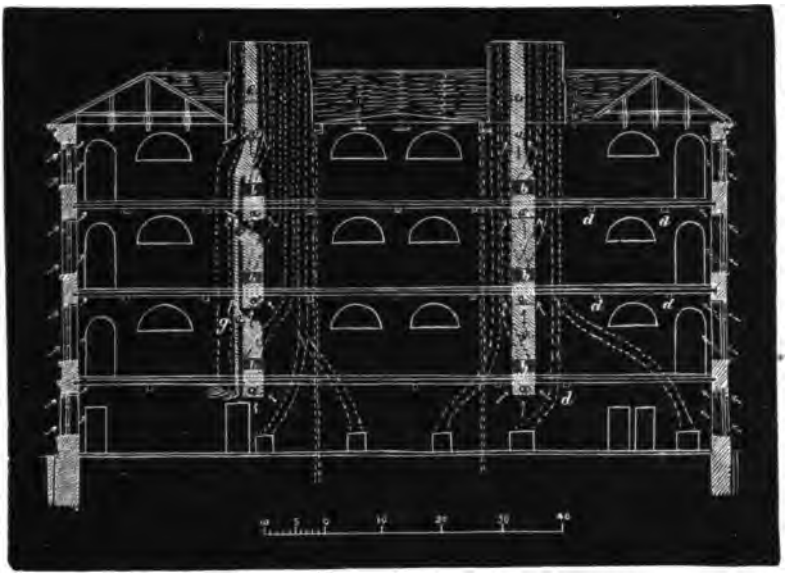
The wards are double, each of them 106 feet by 23 feet, and 13 feet 6 inches in height; they are divided by a wall, in which are the open fireplaces, ventilators, &c. This wall is perforated with large circular openings, to allow a free communication for the air from window to window, which can be regulated according to the direction of the wind.

The admission of cold air into buildings of this nature requires great care, as the slightest draught upon the patients would be productive of the worst consequences; it should be distributed as much as possible over the whole room. This effect is attained by forming each window into a kind of louvre. When open, as shown in Fig. 337, the sash is at an angle of inclination, causing the cold air to enter above the heads of the patients, as

indicated by the arrows, no beds being placed immediately under the windows.

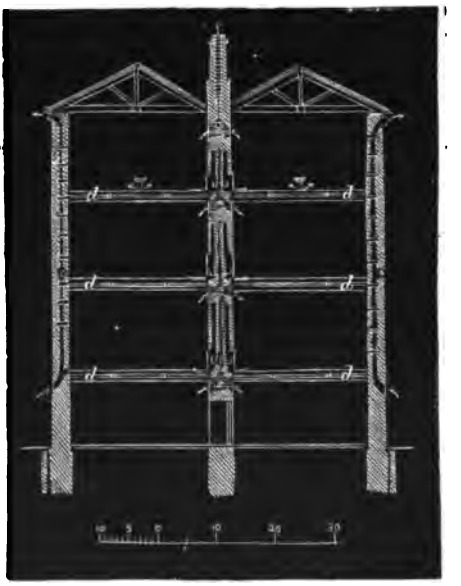
Cold air is also admitted to the centre of the rooms at the table foot, as

Fig. 337.



shown upon the upper floor in Fig. 338, at a sufficient distance from the beds to produce no inconvenience. The outside walls are built hollow, having an air-vent *c*, 3 inches wide, communicating with the atmosphere by air-holes at the top and bottom. A current of air is thus established, which prevents the deposition of moisture on the walls. From this vent, the cold air is conveyed by an air-channel *d*, formed along the ceiling by the bearers or beams which carry the floor, and admitted at the table leg, where there is a valve which can be closed at pleasure.

Fig. 338.



The contaminated air is removed from the several wards by exhaustion, on a very simple plan, as shown in the engraving. The fire-places are placed back to back, having a malleable iron air-chamber between them, protected from the action of the fire by fire-clay lining. It is perforated at the top and bottom, to allow the atmosphere, which is supplied to it from the room below, to become heated and pass off by the ventilating flue *c* (the dotted lines in Fig. 337 are smoke-flues). Thus the heat of the fire in the ward above is made to ven-

tilate the one below. The uppermost ward is ventilated upon the same plan, although there is of course no fire-place above it; the ventilating flue, receiving additional heat at each story, becomes sufficiently warmed to draw the vitiated air from the uppermost. The power of the ventilating flue is increased by burning a jet of gas on either side of the iron chamber, which jets are shown in all the ventilators, Fig. 338, and are intended not only to assist the ventilation in summer, or when the different fires are not burning, but also to serve for lighting the wards.

Advantage is also taken of the heat of the gases from the fires of the bake-, brew-, and boiler-houses, which are conducted along insulated iron cylinders encased with brick. The gases from these cylinders are conveyed into one flue *g*, while the heated air is conveyed into the ventilating flue *e*. The heat generated from these flues is of course very great, and, on trial, was found to be so powerful, that the architect was enabled to make use of the superfluous warm air to supply additional heat to the wards when required.

The extreme simplicity of this method, and the extraordinary ventilating power obtained, render it in every way adapted to heating or ventilating an infirmary, or large rooms where numbers of people assemble.

For churches, theatres, and indeed all rooms where large numbers of persons are constantly congregated together, a thorough supply of pure, fresh, but at the same time genial air, is an object of the greatest consequence, although formerly it received little attention. Churches are, for the most part, filled with roasted or over-heated air, whilst the upper parts of theatres cannot be endured by persons of delicate constitution. The necessity of attending to proper ventilation is now, however, generally recognized, and numerous plans have been proposed and experiments undertaken to effect this in the most complete and economical manner. The plan adopted for the Infirmary at Newcastle is only one of many others which have been tried with variable success. The problem to be solved is the economical supply of an adequate quantity of pure and properly warmed air to a certain area in a given space of time; the amount of air required varying of course with each individual case. It appears that hygeists are not agreed as to the mean quantity of air required by a number of individuals during a given time, and until this point is definitively settled, the calculations which must obviously be based upon it will necessarily differ according to the standard assumed by each observer. There can be no doubt, however, that it is preferable to have a supply of fresh air in excess of what is required rather than a deficiency, although the latter has frequently been the practice.

In the former House of Commons, which was warmed and ventilated under the superintendence and according to the plans of Dr. Reed,* the air was supplied from Old Palace Yard to the basement of the building. Passing first through a fibrous veil 42 feet long by 18 feet 6 inches deep for the exclusion of visible soot, the air arrived at the heating apparatus, consisting of large chambers intersected by steam pipes, and proceeded from thence to other chambers, where it was mixed with cold air and brought to any required temperature. The floor of the house was double, and the space below the floor could be connected by means of valves with the hot-air chamber. The floor was perforated by a great number of apertures, and these were covered with hair-cloth, so that the hot air in escaping from the floor into the body of the house was well diffused, and no perceptible current was experienced. Having performed its functions, the vitiated air ascended to the ceiling, which was also double and perforated, in the same manner as the floor, whence it was carried off by the draught created by a powerful fire under

* Author of the "Theory and Practice of Ventilation."

a chimney shaft erected in another part of the building. In the present House of Commons, there seems to have been no plan followed, and, consequently, there is great confusion about the heating arrangements. (See Dr. Percy's report.)

The plan adopted by Mr. Barry for warming and ventilating the House of Peers, the royal ante-chamber, and the public lobby, differs from that just described both as respects the admission of the air and its removal. The floors of the rooms are not perforated, and are heated in the first instance simply by the passage of hot air below them; the hot air then escapes by passages along the external sides of the rooms to the ceiling, which is divided into two compartments, the one for the admission of the warm air, entering at the sides, and the other for the exit of the vitiated air. The warm air after passing below the floor to the roof becomes somewhat cooled, so that its temperature on entering the ceiling is a few degrees lower than that actually present in the room; it consequently descends to the level at which it is at once heated again, and, deteriorated by combustion, respiration, &c., rises through the centre of the room, passing through the ceiling to a foul-air chamber above, whence it is conducted to a chimney and carried off by the peculiar motive power first suggested by Dr. Richardson for the production of draught. This power consists of a jet of steam, which, when produced under pressure of 32 lbs. to the square inch, is capable of setting 217 times its bulk of air in motion; 10,000 cubic feet of air are thus gradually diffused through the three apartments per minute, no draught of any kind is perceptible, and no inconvenience is experienced from dust or other solid particles being carried mechanically forward by the air, as is said to be the case when the air enters from the floor.

In other large buildings, as at the prison in Millbank, warm air is admitted at the ceiling, and carried off by the draught of a chimney in connection with the sides or lower part of the rooms. At the Reform Club, and at the Hospital for Consumptive Patients at Brompton, warm or cold air is forced forward by a fan or pumped by a steam-engine in the basement, into channels which convey it over the whole building; being subsequently allowed to escape through the chimneys and other apertures.

Although it is not probable that the same arrangements can be adopted for heating and ventilating all extensive buildings, differing in construction and in the uses to which they are applied, yet it is to be hoped that the various experiments which have been tried upon a large scale may lead to a sound knowledge of the fundamental principles to be observed for securing an object so conducive to health and comfort.*

The extent to which the air is vitiated by respiration, transpiration, and the combustion of illuminating materials is estimated by Péclet as follows:

The respiration of an individual has been ascertained to vitiate nearly 12 cubic feet of air per hour. The water exhaled by the lungs and skin amounts to 589 grains (0.084 lb.) in the same time; and supposing the air to be at a temperature of 59° F., and to take up about half of the quantity of moisture it is capable of sustaining at that temperature, which is about the average quantity it does take up, there will be required in round numbers per individual per hour, 212 cubic feet of air, to remove all the exhalations from the skin and lungs.

The substances employed for giving light require oxygen from the air in proportion to the amount consumed, and if $\frac{1}{3}$ of the oxygen contained in the

* Examples of Gen. Morin's system, and of large halls, churches, and theatres in England successfully warmed and ventilated on Mr. Constantine's plan, are given in the book of the latter on "Practical Ventilation and Warming" (London: Churchill). See also Box, "Practical Treatise on Heat" (London: Spon).

air be the quantity abstracted by the combustion, candles of 6 to the lb. will each require about 10 cubic feet, wax candles about the same quantity, and oil or lamps with large burners about 40 cubic feet per hour.

The quantity of carbon consumed in the process of respiration amounts to about 155 grains per hour, and this, calculated on the principles already referred to, would afford 73 units of heat; but a large portion of this heat is required to retain, in a state of vapour, the moisture exhaled—amounting, as stated above, to 589 grains—and is not available as sensible heat: the quantity is thus reduced to 48 units of heat, which would be in itself sufficient to heat the amount of air required for respiration to a proper temperature, if the heat so communicated were not dissipated by transmission through the walls and windows of dwellings. The loss of heat from these sources has been estimated for a difference of temperature of 36° F. between the external and internal air, and an intermittent system of heating, at about 7 units of heat per hour per square foot, for walls of 1 foot thickness, and at about 8 units for every square foot of glass window surface. From these data, an approximate estimate may be made of the amount of air to be supplied in each case of practical application, and of the amount of heat required to be communicated to it under different circumstances.

Professor Thomson has thrown out the idea that air may be heated for warming and ventilating dwellings by mechanical agency solely, as by a water-wheel or with the aid of a less quantity of fuel in a steam-engine, than could be made to produce the same amount of heat in a direct manner. On the general principles of the dynamical theory of heat, he states that "it is mathematically demonstrable, that any substance may be heated 30° (Fahr.) above the atmospheric temperature by means of a properly contrived machine driven by an agent spending not more than $\frac{1}{35}$ of energy of the heat communicated; and that a corresponding machine, or the same machine worked backwards, may be employed to produce cooling effects requiring about the same expenditure of energy in working it to cool the same substance through a similar range of temperature. When a body is heated by such means about $\frac{34}{35}$ths of the heat is drawn from surrounding objects, and $\frac{1}{35}$th is created by the action of the agent; and when a body is cooled by the corresponding process, the whole heat abstracted from it, together with a quantity created by the agent, equal to about $\frac{1}{35}$th of this amount, is given out to the surrounding objects." As no such method of heating air has yet been practically employed, we must refer the reader, for the theoretical details on this very interesting topic, to the author's paper in the Phil. Mag. for February 1854.

Application of Fuel to Vaporisation.—Fuel is used very extensively for the conversion of liquids into vapour. For this purpose, the heat produced by the combustion of the fuel is communicated to the liquid, through the medium of a metallic vessel, or sometimes the current of heated gases is carried rapidly over the surface of the liquid to be vaporized In the first, the material of the vessel and its thickness affect the transmission of the heat, but not to a degree which practically interferes with work at the temperatures ordinarily employed in the arts.

The quantity of heat which can be passed through the metal of boilers or similar vessels in a given time is, however, an amount which can be measured, as it is within the range of well-defined laws and is not an arbitrary or doubtful matter. Metals possessing different degrees of conductivity are used in the construction of vessels which hold liquids whose thermal conductivity and viscosity also range between limits more or less large, and the processes used in heating these vessels, and the temperature to which they are submitted (or to which it may be desired to submit them) are materially

diverse, so that, with such varying elements, it becomes useful to have the means of learning what result may be expected.

The subject has been investigated principally by Péclet,* Wiedmann and Franz,† Clerk Maxwell, Ängström, and Prof. Tait, and has been expressed somewhat differently by each. Clerk Maxwell‡ proposed the following formula:—

$$H = \frac{abtk}{c}(T - S)$$

where ab = area of plate
c = thickness of plate
t = time
k = specific thermal conductivity of material
H = whole heat conducted in time t
$T - S$ = the difference of temperature which causes the flow.

That is to say, the flow of heat in a given time is a constant quantity, and is proportional to the area and to the difference of the temperatures at the two surfaces, and inversely to the distance between them, or the thickness of the metal.

As determined by Ängström, as much heat will pass, in one minute, through each square centimetre of plate iron, 1 centimetre thick, as will suffice to raise 1 gram of water through 9.°77 C., the difference of temperature between the iron and source of heat being 1° C., and the temperature of the iron about 51° C.

Thus, if the temperature of water and iron in a boiler were 51° C., and the temperature of a flame striking the boiler surfaces were 1000° C., the amount of heat passing through 1 square centimetre of the plate, supposing it to be 1 centimetre thick, would be

$$Q = 9.77 \times S\frac{1000 - 51}{e}T$$

where Q = quantity of heat in gram centigrade units
S = area in square centimetres
e = thickness of plate in centimetres
T = time in passing.

Assuming one minute as the time, we have

$$Q = 9.77 \times (1000 - 51) = 9271.73;$$

that is, in one minute, the temperature of the furnace being 1000° and the water 51°, there would pass through a square centimetre of boiler plate 1 centimetre thick, as much heat as would raise 9271.73 grams of water through 1° C.§

Some very interesting practical limitations to the strict application of these laws in the case of steam boilers have been pointed out by Mr. W. Anderson, who investigated the thermo-dynamic questions connected with the generation of steam‖ from the point of view that, as he expressed it, "A steam pumping-engine which furnishes water under high pressure to raise loads by means of hydraulic cranes, is not more truly a heat-engine than is a simple boiler, for the latter converts the latent energy of fuel into the latent energy of steam just as the pumping-engine converts the latent energy of steam into the latent energy of the pumped-up accumulator or the hoisted weight." In this view, he applied to the steam boiler the general

* *Traité de la Chaleur.* † *Pogg. Ann.*, lxxxix. p. 497. ‡ "Theory of Heat," chap. xviii.
§ See On the Design and Use of Steam Boilers, by F. J. Rowan: "Brit. Assoc. Reports," 1878; "Engineering," vol. xxvi. pp. 164, 283.
‖ On the Generation of Steam and the Thermo-dynamic Problems Involved: Inst. C.E. lectures on "Heat in its Mechanical Applications," 1883-4.

principle announced by Sadi Carnot in 1824—viz.: "That the proportion of work which can be obtained out of any substance working between two temperatures depends entirely and solely upon the difference between the temperatures at the beginning and end of the operation—that is to say, if T be the higher temperature at the beginning, and t the lower temperature at the end of the action, then the maximum possible work to be got out of the substance will be a function of $(T-t)$. The greatest range of temperature possible or conceivable is from the absolute temperature of the substance at the commencement of the operation down to absolute zero of temperature, and the fraction of this which can be utilized is the ratio which the range of temperature through which the substance is working bears to the absolute temperature at the commencement of the action. If W = the greatest amount of effect to be expected, T and t = the absolute temperatures, and H = the total quantity of heat (expressed in foot-pounds or in water evaporated, as the case may be) potential in the substance at the higher temperature T at the beginning of the operation, then Carnot's law is expressed by the equation:—

$$W = H\left(\frac{T-t}{T}\right).$$ "

In order to show the application of this law to the case of a steam boiler, Mr. Anderson supposes that the fuel used is pure carbon, such as coke or charcoal, the heat of combustion of which he takes at 14,544 units, that the specific heat of air and of the products of combustion at constant pressure is 0.238, that only the quantity of air theoretically requisite to supply oxygen for the combustion of the carbon is employed, and that the temperature of the air is 60° F. or 520° absolute. T, then, represents the absolute temperature of the furnace, which he calculates as follows:—

"1 lb. of carbon requires 2⅔ lbs. oxygen to convert it into carbonic acid, and this quantity is furnished by 12.2 lbs. of air, the result being 13.2 lbs. of gases, heated by 14,544 units of heat due to the energy of combustion; therefore:—

$$T = 530° + \frac{14{,}544 \text{ units}}{13.2 \text{ lbs.} \times 0.238} = 5.150° \text{ absolute.}$$

The lower temperature, t, we may take as that of the feed water, say at 100° or 560° absolute," and supposing the waste gases reduced by artificial means to that temperature, then the proportion of heat which can be realized is:—

$$= \frac{5150° - 560°}{5150°} = 0.891;$$

"that is to say," remarks Mr. Anderson, "under the extremely favourable, if not impracticable, conditions assumed, there must be a loss of 11 per cent."

In investigating the numerical value of H, which is the potential energy to be derived from 1 lb. of carbon, the specific heat of carbon being 0.25, and the absolute temperature of air 520°, the following figures are used:—

	Units.
1 lb. of carbon × 0.25 × 520 . . . . . =	130
12.2 lbs. of air × 0.238 × 520 . . . . . =	1,485
Heat of combustion . . . . . =	14,544
	16,159
Deduct heat-equivalent to work of displacing atmosphere by products of combustion raised from 60° to 100°, or from 149.8 cubic feet to 161.3 cubic feet	32
Total units of heat available	16,127

Equal to 16.69 lbs. of water evaporated from and at 212° F. Hence the greatest possible evaporation from and at 212° from 1 lb. of carbon is

$$W = \frac{16{,}159 \times 0.891 - 32}{966 \text{ units}} = 14.87 \text{ lbs.}$$

Mr. Anderson has shown the application of this method of calculation to the specific case of the results of trials with an 8-horse portable engine boiler at Cardiff, which "were carried out with great care and skill by Sir Frederick Bramwell and the late Mr. Menelaus," in 1872, and are recorded in vol. ix. of the Journal of the Royal Agricultural Society.* The temperature of the furnace was not determined, on account of the absence of a trustworthy pyrometer, but the other data observed were as follows:—

Steam pressure 80 lbs., Temperature	324° = 784° absolute
Mean temperature of smoke	389° = 849° ,,
Temperature of the air	60° = 520° ,,
,, ,, feed water	209° = 669° ,,
Water evaporated per 1 lb. coal, from and at 212°	= 11.83 lbs.
Heating surface	220 square feet
Grate ,,	3.29 ,,
Coal burnt per hour	41 lbs.

"The fuel used was a smokeless Welsh coal, from the Llangennech Collieries. It was analysed by Mr. Snelus, then of the Dowlais Ironworks, and in the following Table are shown the details of its composition, and the weight and volume of air required for its combustion:—

PROPERTIES OF LLANGENNECH COAL.

	Analysis of 1 lb. of Coal.	Oxygen required for Combustion. Pounds.	Products of Combustion at 32° F.	
			Cubic Feet.	Volume Per Cent.
Carbon	0.8497	2.266	25.30	11.1
Hydrogen	0.0426	0.309	7.60	3.4
Oxygen	0.0350			
Sulphur	0.0042			
Nitrogen	0.0145	—	0.18	
Ash	0.0540	—	—	
Total	1.0000	2.572	—	85.5
9½ lbs. nitrogen	—	—	118.90	
6 lbs. excess of air	—	—	74.40	
Total cubic feet of products per 1 lb. coal	—	—	226.40	100.0

The total heat of combustion in lbs. of water evaporated—

$$= 15.06\left\{0.8497 + 4.265\left(0.426 - \frac{0.035}{8}\right)\right\}$$

$= 15.24$ lbs. of water from and at 212°

$= 14.1727$ units of heat.

"The temperature of the furnace not having been determined must be calculated on the supposition that 50 per cent. more air was admitted

* See also "Min. Proc. Inst. C.E.," vol. lii. p. 154.

than was theoretically necessary to supply the oxygen required for perfect combustion. This makes 18 lbs. of air per 1 lb. of coal, consequently 19 lbs. of gases would be heated by 14,727 units of heat. Hence—

$$T = \frac{14{,}727}{19 \text{ lbs.} \times 0.238} = 3257^\circ$$

above the temperature of the air, or 3777° absolute.

The temperature of the smoke, t, was 849° absolute, hence the maximum duty would be—

$$\frac{3777^\circ - 849^\circ}{3777^\circ} = 0.7752.$$

"The specific heat of coal is very nearly that of the gases at constant pressure, and may, without sensible error, be taken as such. The potential energy of 1 lb. of coal therefore, with reference to the oxygen with which it will combine, and calculated from absolute zero, is—

	Units.
19 lbs. of coal and air at the temperature of the air contained 19 lbs. × 520° × 0.238	2,350
Heat of combustion	14,727
	17,078
Deduct heat expended in displacing atmosphere, 151 cubic feet .	422
Total potential energy	16,656

Hence, work to be expected from the boiler—

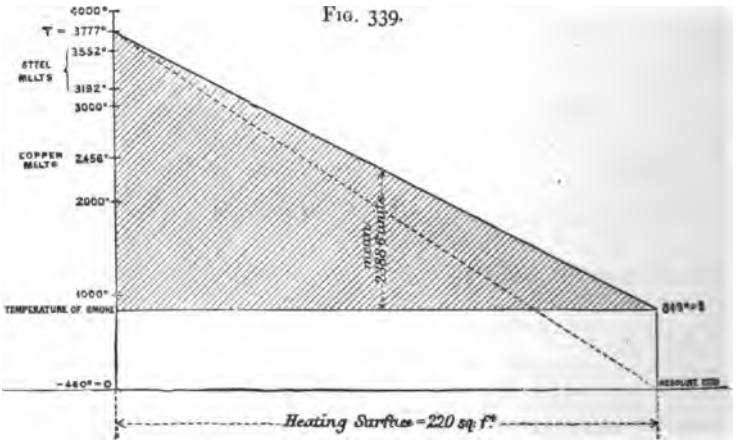
$$= \frac{17{,}078 \text{ units} \times \left(\frac{3777^\circ - 849^\circ}{3777^\circ}\right) - 422 \text{ units}}{966 \text{ units}} = 13.27 \text{ lbs. of}$$

water evaporated from and at 212°, corresponding with 12,819 units. The actual result obtained was 11.83 lbs.; hence the efficiency of this boiler was—

$$\frac{11.83}{13.27} = 0.892.$$"

In order to illustrate fully his view of the action of a boiler as a heat

Fig. 339.



engine, Mr. Anderson proposed the ingenious "indicator diagram," shown in Fig. 339.

Regarding the nature of this diagram, we have the following remarks:—

"The rate of transfer of heat from the furnace to the water in the boiler, at any given point, is in some way proportional to the difference of temperature, and the quantity of heat in the gases is proportional to their temperatures.

"Draw a base line representing − 460° F., the absolute zero of temperature. At one end erect an ordinate upon which set off T = 3777°, the temperature of the furnace. At 849° = t on the scale of temperature, draw a line parallel to the base, and mark on it a length proportional to the heating surface of the boiler; join T by a diagonal with the extremity of this line and drop a perpendicular to the zero line. The temperature of the water in the boiler being uniform, the ordinates bounded by the sloping line, and by the line t, will at any point be approximately proportional to the rate of transmission of heat and the shaded area above t (in Fig. 339), will be proportional to the quantity of heat imparted to the water. Join T by another diagonal with the extremity of the heating surface on the zero line, then the larger triangle, standing on the zero line, will represent the whole of the heat of combustion, and the ratio of the two triangles will be as the lengths of their respective basis, that is, as $\frac{T-t}{T}$ which is the expression we have already used.

"The heating surface was 220 square feet, and it was competent to transmit the energy developed by 41 lbs. of coal consumed per hour = 12,819 u. × 41 = 525,572 units, equal to an average of 2,389 units per square foot per hour; this value will correspond to the mean pressure in an ordinary steam-engine diagram, for it is a measure of the energy with which molecular motion is transferred from the heated gases to the boiler plate and so to the water. The mean rate of transmission, multiplied by the area of heating surface gives the area of the shaded portion of the figure which is the total work which should have been done, that is to say, the work of evaporating 544 lbs. of water per hour. The actual work done, however, was only 485 lbs."

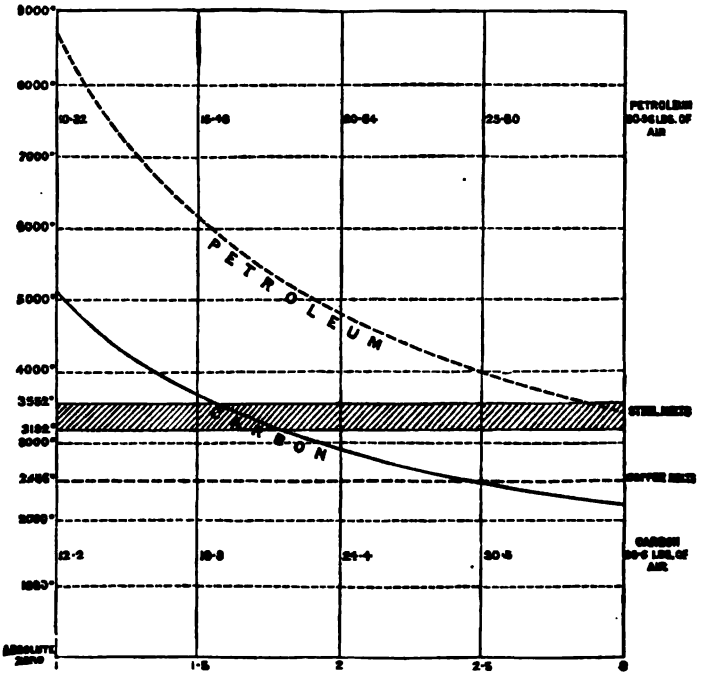
"The great enemy to attaining a high temperature in the furnaces is the quantity of air required to ensure perfect combustion. We have seen that 12.2 lbs. of air are sufficient for the complete combustion of 1 lb. of carbon which will then develop sufficient energy to raise the temperature of the products of combustion to 5150° absolute. In practice, however, a considerable excess of air has to be used, and the energy developed, which is not increased by the excess of air, is expended in heating a greater weight of gases and consequently the temperature is lowered. Fig. 339 exhibits this effect by means of a curve which indicates the temperature of a furnace with from 12.2 lbs. to 36.6 lbs. of air per lb. of carbon.

"Unfortunately no pyrometer exists by means of which the temperature of furnaces can be readily ascertained, but the melting-points of steel have been determined with some accuracy. The late Sir W. Siemens said that cast steel with 1 per cent. of carbon melts at 3192° absolute, whilst steel boiler plates melt between 3462° absolute and 3552° absolute and that the latter is very nearly the melting-point of platinum. On Fig. 339, lines parallel to the base, indicating the extreme temperatures of melting steel, intersect the curve of furnace temperature. To melt boiler plates, the quantity of air admitted should thus not exceed 1½ times the theoretical quantity, and even for cast steel it must not exceed 1¾ times."

"The practical difficulty connected with raising the temperature of the furnace lies in the limited power of boiler plates to stand the high temperature, especially with hard water. With temperatures a little above that of melting steel, there does not appear to be any trouble when the water is soft,

but at higher ranges boilers wear very fast, as, for example, when petroleum is used. This substance is composed of about 0.84 of carbon and 0.16 of hydrogen; 1 lb. of the oil only requires 10.32 lbs. of air for its combustion and yields 22.136 units of heat. The temperature of the furnace therefore with only sufficient air to ensure perfect combustion is 8216° absolute, and the curve on Fig. 340 shows that to bring the temperature down to that of

FIG. 340.



an ordinary furnace would require the use of $2\frac{1}{2}$ times the proper quantity of air."

"The temperature t of the products of combustion cannot be lowered below the temperature of the feed water. In condensing engines this is about 100°, but without enormously extending the heating surface this point cannot be attained, and the temperature of the chimney must be kept at least 100° higher, or at 200°. In the Cardiff engine, the smoke temperature was only about 65° higher than that of the steam, and if by means of feed heaters in the flue the temperature of the smoke could be reduced to 165°, then with 18 lbs. of air to the pound of coal the fall of temperature from $389° - 165° = 224°$, would yield 19 lbs. $\times 224° \times 0.238 = 1.013$ units, competent to raise 11.83 lbs. of feed evaporated per lb. of coal 85.6° or to a temperature of 185.6°, which would still be 103° short of the temperature of the boiler."

"In practice the chimney temperature cannot be lowered to the point indicated unless forced draught be employed, but independently of the advantage gained by improved duty due to the higher temperature of the furnace, there is positive gain if moderate blast-pressure be used. In the experiments made with H.M.S. *Satellite* and *Conqueror* in 1882, it was found that $\frac{1}{4}$ inch of air-pressure in the stoke-hold produced the same result as the ordinary chimney draught, that $\frac{1}{2}$ inch pressure corresponded with the

steam-blast in the chimney, and that 1 inch of pressure was sufficient to ensure about 38 per cent. additional steam, but at a sacrifice of efficiency on account of the boilers being forced beyond their heat-absorbing power. 18 lbs. of air at 60° measure 236 cubic feet, and if forced in under an inch of water-pressure would absorb 1,224 foot lbs. of work, or assuming 50 per cent. duty, 2,447 indicated foot lbs. per 1 lb. of coal consumed. An engine burning 5 lbs. of coal per I.H.P. per hour would absorb 91 units of heat in doing this work; but the heat abstracted from the smoke by lowering its temperature is 1,013 units, hence the power necessary to produce forced draught is only about $\frac{1}{11}$th of that gained by cooling the smoke down to 165°. The necessity, in any case, of building chimneys to carry off the smoke has no doubt deterred nearly every one from trying forced draught, not as a means of temporarily increasing the boiler power, as in the torpedo boats and larger war-ships, but as the proper and rational way of exalting the duty obtained from fuel—namely, by raising the temperature of the furnace and lowering that of the smoke to the utmost extent possible, in accordance with Carnot's theory."

The sources of loss in the practical work of generating steam are, according to Anderson, first, loss by radiation from the furnace to the ash-pit and furnace-door and by radiation and convection from the body of the boiler; second, an indefinite loss, arising from imperfect combustion; and third, loss in the transfer of heat from the heated fuel and gases, first to the boiler plates and then to the water. "In the furnace, the radiation from the incandescent fuel is very intense, and most of the heat is transferred to the boiler-plates by this agency, because very few points of the fuel are in actual contact with the plates and therefore are not in a condition to transmit by conduction. Iron and copper are probably only slightly diathermanous—that is to say, at the thicknesses which occur in practice a very small proportion of radiant heat passes directly through the plate."

"All energy transferred by undulatory movement, whether heat, light or sound, suffers absorption or reflection in passing from one medium to another; thus, in passing through the clearest glass, a ray of light emerges shorn of some of its brilliancy, a part being reflected and a part absorbed. The rays of heat, in like manner, are arrested to a varying extent, depending on the nature of the substance, in part reflected, in part absorbed; and Prof. Tyndall's experiments on fog signals at the South Foreland show that sound is in like manner affected when passing through media of varying density.

"The rate of transfer of heat through a plate varies directly as its thickness, directly as the difference of temperature on its two sides, and probably inversely as its absolute temperature; but, unfortunately, it is impossible to ascertain what the actual temperature of either side of a boiler-plate is. It is quite certain that the side of the plate next the furnace is very greatly below the temperature of the fuel and the flame, because, if it were not, copper furnaces and brass tubes, which melt below 2000°, would very soon be fused; and, on the other hand, on the water side, we have no means of telling how much hotter the plate is than the water. It is evident that the greater part of the radiation from the fuel must be reflected backwards and forwards, keeping up the temperature of the gases, which part with their heat-energy by degrees as they pass along the flues.

"A certain amount of heat-energy passing through a boiler-plate is lost in keeping up the molecular motion of an imperfectly elastic material. It may be likened to the flow of water through a pipe inclined so as to be 'in train,' that is, till the rate of inclination exactly equals the retarding force of friction. The longer the pipe the greater amount of heat will disappear in overcoming friction, and so the thicker the boiler-plate the greater difference

there will be in the temperature of its two sides, and the greater loss of heat in the passage of a given quantity.

"Again, at the surface, where the heated gases touch the plates, and where the plates touch the water, there is a change of density and of material, and consequently a certain amount of loss arises. We do not know sufficient of the nature of heat-motion to say what takes place in its transfer by conduction from one body to another; but it is certain that wherever there is a joint, even in a bar of uniform material, there a certain amount of resistance and loss arises."

"In the indicator diagram (Fig. 339), we have assumed that the rate of transmission of heat from the gases to the water is in direct proportion to the difference of temperature, but this is probably not strictly correct, because the conductivity of substances varies inversely as the temperature, probably as the absolute temperature; hence the rate of transfer of heat at the furnace end will be slower in proportion than at the chimney end, but to what extent it is impossible to say, because the mean temperature of the boiler-plates is unknown. It is certain, however, that it is below even the melting-point of lead, or 630° F., because lead safety-plugs are frequently used, even in locomotives, and they do not melt out unless there be a want of water. If we assume the mean temperature of the plates at the furnace end to be 500°, and that of the chimney end 350°, then the rate of transmission at the cooler end will be about 18 per cent. greater than at the hotter. Were it not for the imperfect absorption of radiant heat and reduced conductivity, caused by high temperature, ebullition over and about the furnace would be so violent that uncontrollable priming would surely take place."

"The rate of transmission of heat by the heating surface of a boiler can thus be approximately calculated. In the case of the Cardiff boiler, the combustion of 41 lbs. of coal per hour was capable of yielding 525,572 units of heat. The mean temperature of the gases was estimated at 2313° absolute, that of the water in the boiler 784°; hence, the mean difference of temperature was 1529°. The heating-surface being 220 square feet, U, the number of units of heat absorbed per square foot per difference of 1° per hour would be—

$$U = \frac{525{,}572 \text{ units}}{1529^\circ \times 220 \text{ square feet}} = 1.56 \text{ unit.}$$

"In this case, glowing fuel and heated gases impart, chiefly by radiation and convection, their energy to water at a lower temperature. The action is the inverse of that which takes place where hot water or steam is used for heating buildings; we might expect, therefore, according to the doctrine of exchanges, that the work done per unit of surface and difference of temperature would be approximately the same. In vol. xviii., Min. Proc. Inst. C.E., will be found a curve from which the units of heat given out by a 2-inch wrought iron hot-water pipe may be ascertained. For a difference of 190° between the temperature of the water and the air being heated, 590° units per square foot per hour were given out; this is equal to 3.1 units per square foot per difference of 1° per hour, or about double the amount realized at the Cardiff trials. This is accounted for partly by the fact that the plates and tubes of the boiler of the portable engine were, on the whole, thicker than the metal of the heating-pipes, partly by the conducting power of the surfaces having been reduced in consequence of their high temperature, but chiefly by the circumstance that the temperature of the furnace-plates, for a considerable portion of the smoke-run, is very much less than that of the glowing fuel and gases, hence the mean temperature of

the plates would be considerably lower than that of the products of combustion.

"Until a trustworthy pyrometer is found, it will be impossible to determine more accurately the rate of transmission, but it may be stated that in practice 12 square feet of flue-heating surface, measuring only the half over the gases, or 10 square feet of small tube surface, measured in the same way, will transmit the heat necessary to evaporate 1 cubic foot of water per hour from and at 212°. The French allow 1 square metre or 10.76 square feet per horse-power, but the value of a French boiler horse-power has not been accurately defined."

Regarding the question of velocity of gases through flues and tubes, constituting the heating surface of boilers, Mr. Anderson states that "from a number of boilers in actual work with chimneys of moderate height," he had "deduced that for a temperature of 400°, a velocity of 10.8 feet per second is admissible; this corresponds to 10 square inches of flue section per boiler horse-power (which he defines as 1 cubic foot of water evaporated from and at 212°), and for a consumption of 1 lb. of coal to 10 lbs. of water converted into steam."

Various methods are adopted in converting liquids into vapour according to the object in view, although the manner of applying the fuel differs but little in principle.

1. Vapour is produced for its motive power and as a carrier of heat, and the operation may then be distinguished as *Vaporization*.

2. The object may be to separate by vaporization and collect by condensation, a more volatile from a less volatile liquid, and the process is then called *Distillation*.

3. The simple removal of a volatile liquid from a substance which is less volatile or fixed is called *Evaporation*.

4. When the liquid that moistens a solid is removed by evaporation, the process is called *Desiccation* or *Drying*.

Vaporization.—It is beyond the limits of the present work to enter on a description of the form, dimensions, thickness, or other particulars connected with the boilers employed for the purposes of raising steam of different degrees of pressure; and we therefore confine ourselves to a few illustrations of the usual and approved arrangements adopted for applying the fuel required to raise steam.

The furnace is placed in the case of cylindrical and oval boilers either below the boiler or in a flue or cylinders within it, so as to be completely surrounded by the surface containing the liquid, and the hot gases are conducted to the chimney by a flue or series of flues, which are brought more or less into contact with the external surface of the boiler, so as to be cooled down to a temperature of about (300° C.) 550° to 600° F., which corresponds with the maximum amount of draught in the chimney. In the locomotive boiler, the barrel of which is cylindrical and contains a number of tubes acting as flues for the hot gases, there is a fire-box built at one end, which is usually of rectangular shape. Water-tube boilers present a different case, and are of such a variety of forms that plans are requisite in describing them. The grate is generally constructed of wedge-shaped bars of cast-iron, the broad part of the wedge being placed uppermost. The extent of grate-surface is regulated by the amount of work to be done, the size of the boiler, and the kind of fuel to be employed. The usual dimensions, when coal is used as fuel, are 1 square foot of grate-surface for a consumption of about 20 lbs. of coal per hour. Tredgold recommended about a square foot of grate-surface for every horse-power of vapour required, which, estimating the coal consumed at 11 lbs. per horse-power (not an unusual rate in early days), would have very much increased the size of the grate.

The following relations between fuel consumed, grate-surface, and heating-surface were given by Mr. Prideaux in an admirable little work on the economy of fuel, in which he advocated the use of compressed air to increase the heat of furnaces:—

Fuel burnt per hour per square foot of fire-grate:

In Cornish boilers	3½ to 4 lbs.
In factory and marine boilers	10 to 16 „
In locomotive boilers	80 to 100 „

The number of square feet of heating-surface in boiler required to evaporate 1 cubic foot of water per hour is:

In Cornish boilers	70 sq. ft.
In factory and marine boilers	9 to 11 „
In locomotives	6 „

The number of square feet of heating surface to each square foot of fire-grate is:*

In Cornish boilers	40 sq. ft.
In factory and marine boilers	13 to 15 „
In locomotives	50 to 70 „

The following proportions of various forms of land boilers were given by Mr. R. B. Longridge in a paper on the "Relative Economy and Durability of Various Classes of Stationary Steam Boilers" ("Proceedings Inst. Mech. Engineers," vol. for 1859):—

	Area of Fire-grate.	Heating-surface.
A. Cylindrical boiler with 2 flues	38 sq. ft.	590 sq. ft.
B. „ „ „ 2 „	35 „	540 „
C. „ „ „ 2 „	30 „	463 „
D. „ „ „ 5 „	30 „	530 „
E. Multiflued „ „ 7 „	52 „	697 „
F. Galloway „	30 „	499 „
G. „ „	38¼ „	898 „
H. „ multitubular boiler	30 „	599 „
I. Multitubular boiler	30 „	454 „

The rate of consumption of slack coal in these boilers is given in the following table in lbs. per square foot of grate-surface per hour:—

	A.	*B.*	*C.*	*D.*	*E.*	*F.*	*G.*	*H.*	*I.*
1st expt.	18.1	20.5	11.8	20.4	12.9	17.1	23.8	11.9	15.0
2nd „	—	—	9.1	21.8	—	—	23.2	9 2	15.6
3rd „	—	—	—	—	—	—	—	—	15.4

Mr. Robt. Wilson (in "A Treatise on Steam Boilers") gives the following as the average rates of combustion in various boilers using semi-bituminous coal. Similar figures are given in Rankine's "Steam-engine and other Prime Movers."

	lbs. per sq. foot of Grate per Hour.
Lowest rate of combustion in Cornish boilers	4
Usual „ „ „	10
„ „ in externally fired and internally fired factory boilers	10 to 18
„ „ in marine boilers	14 to 26
„ „ in locomotive boilers with blast pipe	60 to 130

The rate of combustion varies with different classes of fuel in different localities, but with solid fuel is practically governed by the chimney draught and the combustibility of the fuel.†

The maximum rate of combustion of semi-bituminous steam coal with

* See also "Fuel, its Combustion and Economy," pp. 206, 207, Weale's series; D. K. Clark's "Manual of Rules, Tables, and Data for Mechanical Engineers," 3rd edition, pp. 768-821.

† See R. Wilson, "A Treatise on Steam Boilers," p. 272.

air-admission through the grate and above the fire, and with chimney draught, is about 40 lbs. per square foot of grate-surface per hour, but the evaporative economy* decreases rapidly with a combustion exceeding 30 lbs. The maximum rate of combustion of semi-bituminous steam coal with air-admission through the grate only is about 35 lbs., but even below this rate the intense heat given out by these coals has been found to fuse the bars rapidly. Their evaporative economy decreases with a more rapid rate of combustion than 26 lbs.

These remarks apply to combustion in furnaces the air-supply to which, as well as the rate of travel of the hot gases over the heating-surface, is governed by chimney draught. The use of mechanical means for supplying the air for combustion enables higher rates of combustion to be usefully employed as the rate of escape of the hot gases is under control. This system has not yet been applied in practice in a complete form, but approximations† to it have been made in several instances, which have shown the economy which is possible by such means.

The boiler-surfaces should be placed at some distance from the surface of fuel on the grate. If placed too near, as is very frequently the case, the flame may be extinguished, or much smoke and imperfect combustion produced by the cooling effect of the boiler and its contents, which are always at a temperature greatly below that of the flame. A distance of 14 to 16 inches between the grate and the bottom of the boiler has been considered sufficient when coal is the fuel, 30 inches for wood, 20 for turf, and 24 for coke, but in most cases they may probably be increased with advantage to ensure complete combustion of the gases before they come into contact with the surfaces to be heated. With gas firing, a height of 22 to 24 inches has been found by experiment to be the most suitable for the combustion chamber.

The advantage of flues in bringing the heated gases into contact with the sides of the boiler was disputed by many engineers for a considerable time, and the whole value of the fuel was attributed to the radiant heat it afforded; but this erroneous view has long since been disproved, and arose from the fact of far too large a quantity of air being admitted to the fuel, which cooled the products of combustion to such an extent as to render them nearly valueless as a source of heat.

With a view to test this opinion in a practical manner, a commission of the Industrial Society of the Grand Duchy of Hesse experimented on the relative effect produced by a different arrangement of the furnace and flues in relation to the boiler, with different kinds of fuel, the same boiler being employed in all the experiments, although the furnace was differently arranged in each case.

The following were the arrangements tried:—

A. No flues were constructed, but the boiler was freely suspended above the fire.

B. The bottom of the boiler was alone exposed to the radiant heat of the fire, and the heated gases circulated once round the boiler in a flue which commanded the entire height of the sides of the boiler.

C. The bottom of the boiler was exposed to the radiant heat, but the heated air circulated twice round the sides of the boiler, the flue being only one-half as high as in experiment *B*.

D. The fire was arched over, leaving an aperture in the centre of the arch, through which the hot gases impinged upon the bottom of the

* For methods of calculating efficiency of furnaces, see Rankine, "Steam Engine and other Prime Movers;" T. Box, "Practical Treatise on Heat," &c.

† See C. Wye Williams, "Fuel, its Combustion and Economy;" Rankine, "Steam Engine &c.;" J. F. Flannery, "Proc. Inst. N.A.;" J. Howden, "Proc. Inst. N.A."

boiler, and circulated freely and simultaneously round the sides in an annular space before escaping to the chimney through several apertures at the sides.

E. The bottom of the boiler was heated by direct radiation, and the heated air traversed the sides of the boiler in two flues, one on either side, which joined again above the fire, and each of which was consequently only the half of the circumference of the boiler in length.

F. The bottom was heated by radiation, and the hot gases traversed simultaneously two flues placed on either side, each making the complete circuit of the boiler.

The following table contains the results of the experiments; the figures indicating the quantities of fuel employed for producing a similar effect in the same space of time; the highest corresponding with the most defective plan:—

Wood . .	*F.*	*E.*	*C.*	*B.*	*D.*	*A.*
	63	68.8	68.9	72.19	72.23	100
Turf . . .	*F.*	*C.*	*D.*	*E.*	*B.*	*A.*
	53	66	71	72	76	100
Coal . . .	*C.*	*F.*	*B.*	*F.*	*D.*	*A.*
	73	73	83	85	91	100

The result of these experiments clearly shows, in the first place, the advantage of allowing the hot gases to circulate in flues round the boiler; secondly, that, with suitable flues, the saving of fuel is much greater when turf and wood are employed than is the case with coal; in the case of turf, nearly the same effect being produced with ½ the quantity, ⅓rd being saved in the case of wood, and ¼th only in that of coal. It appears, moreover, that two flues are more effective than one, and the arrangements indicated in experiments *E* and *F* are generally the most beneficial. The arrangement adopted in experiment *D* does not appear to have had a fair trial. If the arch were employed in conjunction with a system of flues, it is probable the effect would have been greatly increased. Coal radiates much more heat than either wood or turf, but, any great depth of fuel not being adapted to the consumption of coal, a much larger quantity of air generally passes through the grate and furnace than is required for its complete combustion, and this of course tends to diminish the temperature of the gaseous products, and accounts for the diminished action of the flues.

Fig. 341.

The arrangement of the furnace which is generally adopted in this country, and considered the most economical, is that in which the furnace is surrounded by the boiler, as shown in Fig. 341. This is the construction adopted in the large boilers employed at the Cornish mines, which are celebrated for the large amount of work performed at a small cost of fuel. The outer cylinder is of very large dimensions, being often 6 feet in diameter and 60 feet long. The hot gases, after passing through the centre of the boiler, return through the flues *o o* before escaping to the chimney. These

boilers are often worked at a pressure of 75 lbs. to the inch and upwards.

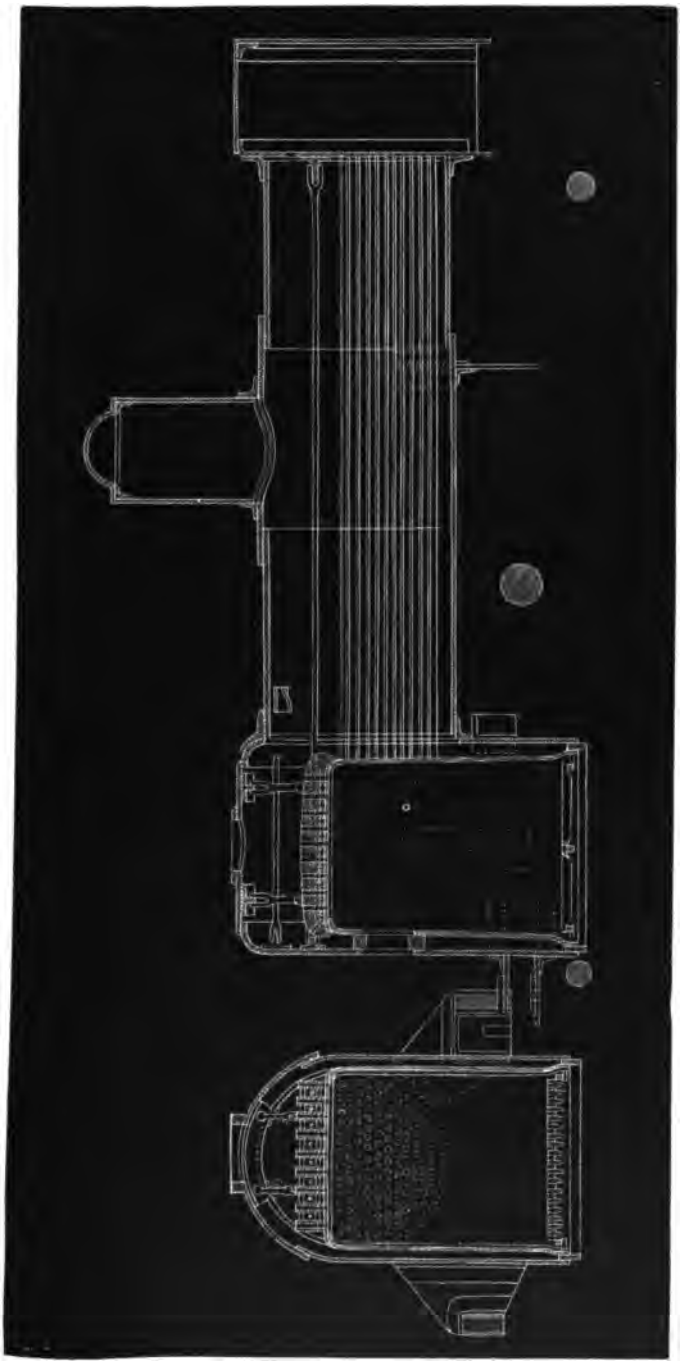


FIG. 342.

The grate is large in proportion to the consumption of fuel, as well as the

heating-surface, so that the gases escape to the chimney at a temperature only just sufficient to maintain a draught.

In marine engines and locomotives, where space must be economized and high chimneys cannot be employed, while a very great consumption of fuel is necessary to raise the requisite amount of steam and create the draught, a totally different construction of furnace is required. Fig. 342 shows the construction of the furnace and boilers of locomotives, the general principle of which consists in burning the fuel in front and below the great body of the boiler, in a space surrounded on all sides except the bottom by a thin stratum of water, enclosed between strong wrought-iron or steel plates, and which forms a portion of the boiler; the heated gases from the fuel, before escaping to the short chimney, are obliged to pass through a numerous series of metal tubes surrounded by the water of the boiler, by which contrivance the heating-surface is enormously increased.

Figs. 343–346 show the design of ordinary marine boilers in use. The

Fig. 343.

Fig. 344.

furnace is placed inside the boiler as in Cornish boilers, and the hot gases are returned to the front of the boiler by numerous tubes also inserted through the water space. More attention seems to have been paid to circulation of the hot gases than to the water circulation in the design of this type of boilers.

The illustrations have been supplied by Messrs. Lindsay Burnet & Co., of Glasgow, and illustrate the best practice in the construction of marine boilers of the kind known as "shell" boilers, as distinguished from "water-tube" boilers. Figs. 343 and 344 are sections of a small boiler, showing the furnace and combustion chambers so constructed that no double thicknesses of plate or rivet heads are exposed to the direct action of the fire. Consequently, a higher temperature may with safety be employed than would otherwise be practicable. Fig. 343 is half elevation, showing smoke-box, furnace front, and chimney, and half section

Fig. 345.

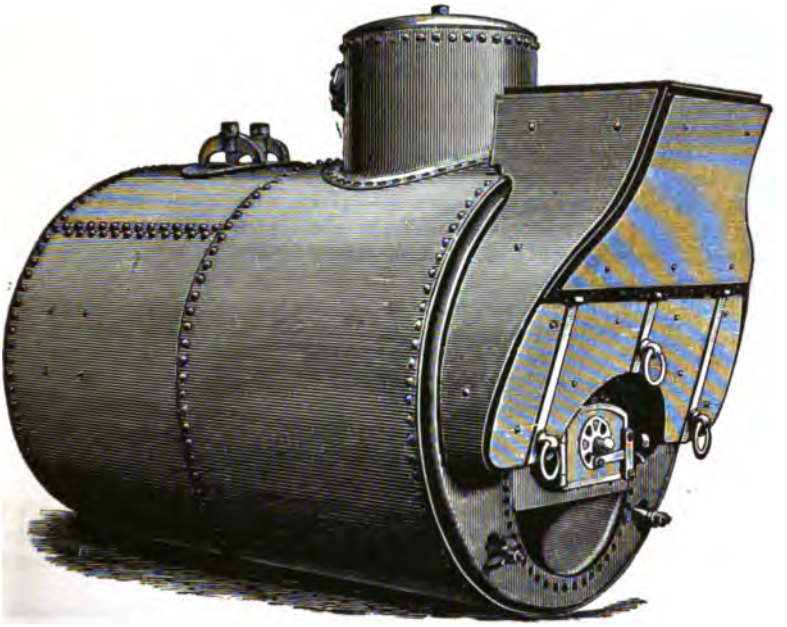
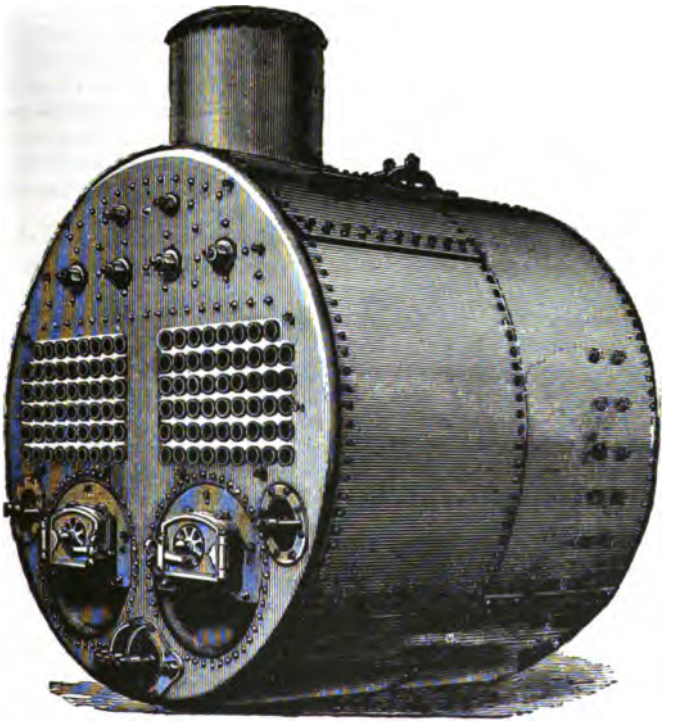


Fig. 346.



through the tubes. Fig. 344 is a longitudinal section through the entire boiler.

Figs. 345 and 346 show respectively single and double flued marine boilers in elevation, Fig. 345 having the smoke-box or "uptake" added in front outside the ends of the horizontal tubes.

These boilers are made of various sizes up to 16 feet outside diameter, and being constructed of steel and by means of elaborate and powerful drilling, flanging, and riveting machines, are worked at pressures of steam up to almost 200 lb. per square inch.

Messrs. Ebelmen and Sauvages undertook a series of experiments, the object of which was the analysis of the gases issuing from the furnace of the locomotive engine. The results obtained from a considerable number of analyses proved the possibility of establishing a definite theory of this important class of furnaces, and showed that these furnaces were much more perfect than they were generally believed to be, and that the combustion is more complete in them than in many others.

The experiments were made on each of the three types of engines used on the Lyons Railway—viz.:

Passenger engines	not coupled.
Mixed traffic engines	4-wheel coupled.
Goods engines	6-wheel coupled.

The composition and nature of the gases varies necessarily with the quantity of air which passes through the fire, and this quantity depends on the tension of the steam at the escape or blast pipe, and the proportions of the nozzle and escape pipes.

The proportion of carbonic acid contained in the gases of the locomotive is greater than is contained in the gases from ordinary fixed engine furnaces, while the proportion of free oxygen corresponding with the excess of air in the draught is less in the locomotive furnace, a result clearly proving that there is a greater useful effect obtained from the fuel.

In the experiments on the passenger engines, and on the mixed traffic engines, the proportion of carbonic acid rose from 12.42 to 18.49 per cent. of the volume of gas, without there being any production of carbonic oxide. The higher percentage represents a result approximating very remarkably to the number, 20.80, which represents the proportion of carbonic acid in the case of combustion *theoretically perfect*, or in which all the oxygen would be converted into carbonic acid.

The combustion in passenger engines is almost perfect, and in the mixed engine, provided the fire is attended to by an experienced stoker, it is nearly as good.

These furnaces produce little or no carbonic oxide. The proportion of the gas rarely exceeds 2 per cent.

The goods engines, the grates of which are often charged with a great depth of coke, produce a greater amount of carbonic oxide; the quantity rose as high as 7.58 when the fire was 40 inches deep.

The composition of the gas varied according to the range of tube from which it was collected. It would certainly be possible to adopt arrangements which would permit of this carbonic oxide being usefully burnt, thus improving the beneficial effect of the fuel in these engines.

During the stoppages of locomotives, or after the closing of the regulator, the gases contain a still larger proportion of carbonic oxide. It often reaches 12 per cent. of the volume.

These results are quite in accordance with practical experience* in reference to the consumption of fuel in different engines. They indicate

* As to this, see also D. K. Clark, C.E., "Railway Machinery;" also "Locomotive Engineering," by Zerah Colborn.

not only a limit to the depth of fire which it is not prudent to exceed, but also what amount of economy can be effected by the intelligent employment of expansion and variable blast pipe, according to the depth of the fuel in the fire.

With reference to the use of the blast pipe in locomotives, Rankine* makes the following observations:—

"The effect of the blast pipe in producing a draught depends upon its own diameter and position, on the diameter of the chimney, and on the dimensions of the fire-box, tubes, and smoke-box. Mr. D. K. Clark, who has investigated the influence of these circumstances from his own experiments, and from those of Messrs. Ramsbottom, Polonceau, and others, has shown that the vacuum in the smoke-box is about 0.7 of the blast pressure; that the vacuum in the fire-box is from $\frac{1}{3}$ to $\frac{1}{2}$ of that in the smoke-box; that the rate of evaporation varies nearly as the square root of the vacuum in the smoke-box: that the best proportions of the chimney and other parts are those which enable a given draught to be produced with the greatest diameter of blast pipe, because the greater the diameter, the less is the back pressure produced by the resistance of the orifice; that the same proportions are best at all rates of expansion and at all speeds; and that the following proportions are about the best known:—

Sectional area of tubes within ferrules .	= $\frac{1}{5}$ area of grate
„ of chimney . . .	= $\frac{1}{15}$ „
Area of blast orifice (which should be somewhat below the throat of chimney)	= $\frac{1}{66}$ „
Capacity of smoke-box	= 3 feet × area of grate
Length of chimney	= its diameter × 4.

If the tubes are smaller, the blast orifice must be made smaller also; for example, if—

Sectional area of tubes within ferrules .	= $\frac{1}{10}$ area of grate,
then area of blast orifice . . .	= $\frac{1}{90}$ area of grate."

The composition of the gases escaping from the furnaces of boilers has been examined by several engineers and chemists. Some of their results will be referred to in connection with the "practical effect of fuel," and others in the section on "gas-fired boilers."

Prevention of Smoke.—The prevention of smoke from boiler fires has attracted great attention in this country. A public meeting was held by circular in 1842, in Leeds, where numerous patentees and others attended; a committee of the House of Commons collected evidence with the view to legislation; whilst the Health of Towns Commissioners have drawn increased attention to the whole subject by an attempt to estimate the many damages the public sustain from unconsumed smoke. Smoke Abatement Exhibitions have also been held in London and Manchester; and large powers for restricting the production of smoke have been placed in the hands of municipal authorities in various localities. Numerous patents, too, have been taken out, and many plans have been suggested as capable of removing or modifying this evil.

Smoke being the result either of an insufficient supply of air or of an excessive supply at too low a temperature, it is extremely difficult, in consequence of the nature of the fuel ordinarily employed in this country, to suggest a plan which shall be applicable at once to the volatile portion of the coal and the coke which remains on the grate.

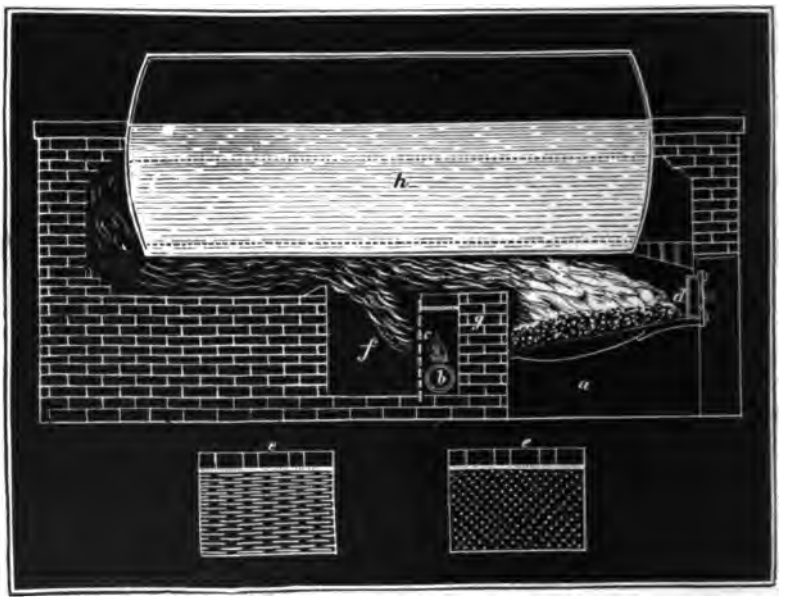
Smoke is produced in greatest quantity on the addition of fresh fuel to the red-hot coke on the grate, and is due to the process of dry distillation,

* "Steam Engine and Other Prime Movers," p. 532.

which immediately takes place, evolving a large portion of gaseous matter from the coal, which there is either not sufficient air fully to consume, or the flame of which is cooled so much by contact with cold surfaces or cold air, as to cause a deposition of solid carbon. The prevention of smoke does not, however, necessarily prove perfect combustion of the fuel; as, if smoke be prevented by greatly limiting the supply of cold air, which may sometimes be done, a large portion of the active power of the coal may ascend the chimney in the form of invisible carbonic oxide, which, from deficiency of oxygen, has escaped conversion into carbonic acid. The analyses of the gases escaping by the chimney will, however, prove whether this be the case or not. On the addition of fresh fuel, an additional supply of hot air is required to consume the volatile products which immediately escape from it, and it is this necessary irregularity, or intermittent nature of the supply, which is so difficult practically to regulate.

Wood and turf may be burnt in a manner so as to reverse the ordinary position of the flame, as is the case with the fires in potters' kilns; this arrangement greatly tends to prevent smoke.

Fig. 347.



A bridge in front of the flame is sometimes employed with indifferent success for the same purpose.

Watt first suggested the idea of introducing a current of cold or hot air into the flame to prevent smoke, and a plan for carrying this out was patented by Robertson. The idea has since been practically applied in a great variety of ways; the air has been conducted in flues by the side or under the fire, or in the chimney, to the back of the grate, and there allowed to come in contact with the flame. The following two plans are illustrations of this principle.

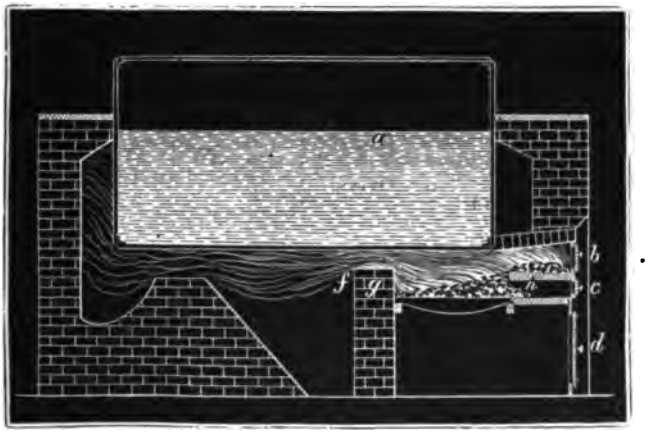
The patent of the late Mr. C. Wye Williams consisted essentially in admitting a current of air behind, or through the fire-bridge, in several small jets or streams, so as readily to mix with the mass of heated hydrocarbons in their escape from the fuel on the grate bars. Fig. 347 shows the manner in which this plan was adapted to a boiler-fire: *h* represents the

boiler; *d* the fire-door lined with fire-clay; *a* the ash-pit, whence the coke on the fire-grate obtains its supply of air; *g* the fire-bridge, behind which is an iron box *c* pierced with a number of small holes, through which the air streams from a tube *b* communicating with the outside; *e e* show plans of different arrangements of the perforations in *c*. The space *f* is intended to act as a diffusion chamber for the more perfect mixture of the air and gases.*

Messrs. Howard & Co. adopted the plan indicated in Fig. 348, which represents a sectional elevation of the boiler and fire arrangements, where *a* is the boiler, *b* the feeding door, *c* door for removing the scars, &c., *d* the ash-pit door, through which the admission of air is regulated by slides, another door, which is not shown, regulated the admission of air to the posterior part *f* of the fire-bridge *g*. The coking plate, *h*, must be built of fire-brick or stone. The coal is first coked on the above plate, and then pushed over on to the grate bars, where there always exists a bright surface of burning coke.

The gases generated in coking a fresh portion of coal pass over this heated surface before they come in contact with a fresh supply of warm air at *f*, and thus an almost perfect combustion of the smoke is obtained.

FIG. 348.



The saving in fuel effected by these plans varied from ¼ to ½ of the whole generally used at that time, and they consequently attracted a good deal of attention. Although a very beneficial result would follow the previous coking of the coal on a broad plate made of stone in front of the fire, and the admission of a fresh supply of air at the back of the fire-bridge, there is no doubt that the only thoroughly satisfactory solution of the smoke question is to be found in the use of gaseous fuel.

Double fires were also invented by Watt, in one of which coke was burned, while the flame of the other, consuming coal, passed over it, or the two were alternately charged with coal, and by means of dampers the flame from the last charge carried over that which had become converted into coke.

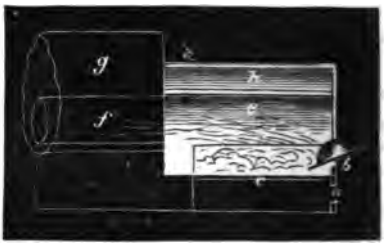
The same idea was carried into practice with some boilers at the cooperage of the St. Rollox Chemical Works, Glasgow, and was found to succeed admirably, as far as the prevention of smoke is concerned; and when the firing was not forced, the brick arch *h* stood well, but otherwise

* For records of results with this plan, see "Fuel, its Combustion and Economy;" and Rankine, "Steam Engine, &c."

it was soon destroyed. Fig. 349 shows a front elevation of the double furnace, Fig. 350 a longitudinal section through one of the fires, and Fig. 351 an isometrical projection of the boiler and furnace partly in section. The boiler is tubular, and was originally furnished with the ordinary central furnace in the interior. Subsequently the furnace was built 6 feet from

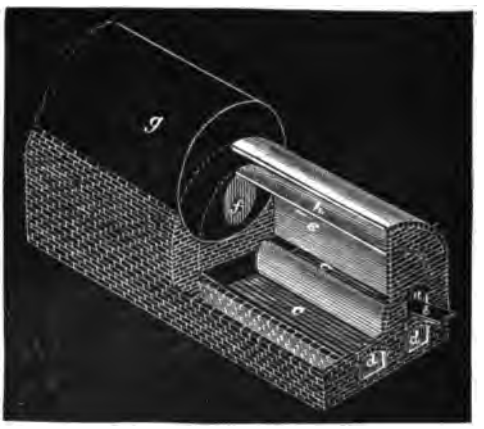
Fig. 349.

Fig. 350.



the front of the boiler *g*, a double arch enclosing an air-chamber *h* being thrown across just above the cylindrical space *f*, which is converted into a flue. Below this arch, two furnace-grates are constructed, which are separated from each other by a low fire-brick wall, but are both in direct communication with the flue *f*; *d d* are the openings to the ash-pits. There are no doors either to the furnaces or ash-pits, but a slanting plate of iron *b* is placed across the furnace-mouth in such a manner that a current of air passes below it and impinges on the fuel, while slack or small coal is heaped upon it so as to fill up the furnace-mouth almost entirely, leaving a very narrow space above it for the entrance of air. The furnaces are charged alternately, so that when the stoker thrusts the slack from the plate into the one grate, the gas generated is brought into contact with the hot gases from the red-hot coke on the other, which must contain a sufficient quantity of uncombined oxygen fully to consume the hydrocarbons. The products from the combustion of the fuel are thus wholly consumed before coming into contact with the comparatively cold surface of the boiler, and no smoke or soot can be deposited, none having been produced. The double arch is of great service in retaining the heat of the furnace; but it appears to us that it would be a more advantageous arrangement if the boiler were placed immediately upon the bridge of the lower arch, and the hot gases were made to return through the central flue to the front, and again by side flues to the back of the boiler, and thence to the chimney; the radiant heat then communicated to the arch would very considerably increase the temperature of the return flues. A similar mode of setting, as applied to a waggon-shaped boiler, is shown in Figs. 352, 353, and 354, Fig. 352 being a front elevation, Fig. 353 a vertical cross section, and Fig. 354 a longitudinal section on the crooked line *a b*, Fig. 353. An arch is thrown

Fig. 351.



over the furnaces to some distance beyond the back of the grates, and forms, with the bottom of the boiler, the first flue through which the heated gases pass from the back to the front of the boiler, to return again to the back through the side flues *f f*, and thence to the chimney; by this arrangement, a very large heating surface is exposed to the action of the flame and gas, although by the intervention of the arch the combustion may be rendered perfect before the gases come into contact with the boiler, and no smoke can be formed.

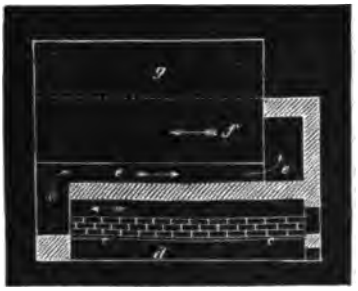
Fig. 352.

Chanter, by inclining the grates so as to allow the coal when converted into coke to fall from the upper to the lower part, succeeded in consuming the smoke entirely in locomotive and other fires. Fig. 355 shows the arrangement applied to a locomotive. *A* is the fire-space; *B B B*, three grates placed at different inclinations; *C* part of the boiler, extending into the centre of the fire; *E*, a door for the introduction of coke through the channel *F*. When $\frac{3}{4}$ths of coal and $\frac{1}{4}$th of coke were consumed on these grates, no smoke was produced.

Fig. 353.

Mechanical Stokers.—The production of smoke in fires being often due to the mode of feeding the fire with fuel, it was supposed that by affording a regular supply at short intervals, it might be entirely obviated.

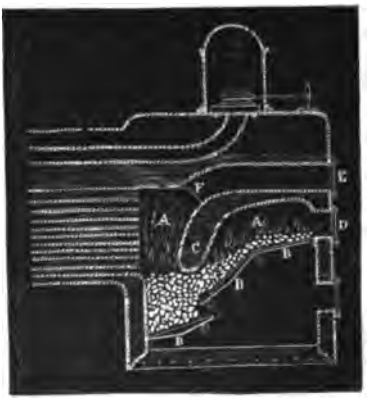
Fig. 354.



Bruton constructed an apparatus in connection with a steam boiler which allowed a certain amount of fuel to be discharged at intervals of half a minute from a hopper on to the grate, and succeeded in almost entirely consuming the smoke of the boiler-fires; the grate in this arrangement was circular, and was gently rotated by machinery.

Collier produced a similar result with a stationary grate by crushing the coal as it descended from the hopper and propelling it by a kind of fan into the red-hot fire-place, while an oscillating motion was communicated by machinery to the bars of the grate, to free them from ashes and clinkers.

Fig. 355.



Both the foregoing arrangements were found far too complicated to be generally adopted, but the following, applied by M. Payen, at Grenelle, is much simpler, and has worked for years without smoke and with great economy of fuel.

Fig. 356 is an elevation of the furnace and fuel-distributor; Fig. 357, a vertical section on the line *C D*; Fig. 358, a vertical section on the line

A B. *A*, fire-place; *B*, fixed grate; *C*, ash-pit; *D D*, boilers; *F*, fire-door; *G*, boiler; *H H*, quadrangular axes supporting four cylinders, with alternate teeth or grooves; *K*, hopper, separated into three compartments, *K' K' K'*,

Fig. 356.

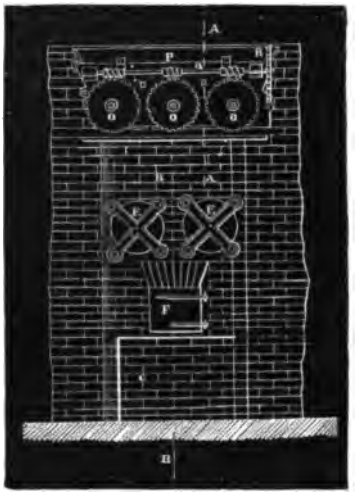
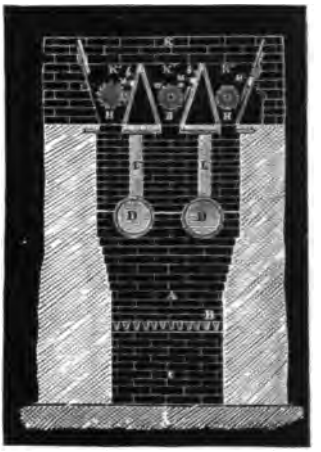
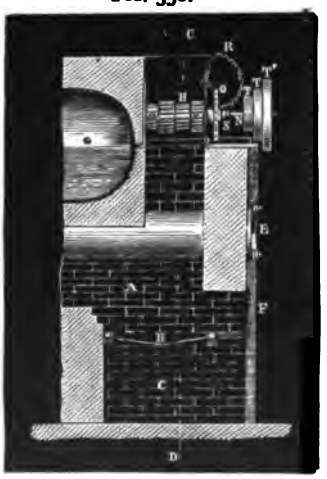


Fig. 357.



into which the broken coal is thrown; *M M M*, slides for regulating the admission of fuel to the grate; *O O*, toothed wheels attached to the grooved cylinders *H H*, and moved by the endless screw *P*, attached to the shaft *Q*; *R*, toothed wheel, set in motion by the endless screw *S*, attached to the shaft *N*, and transmitting motion to the shaft *Q* and the grooved cylinders *H H*.

Fig. 358.



Two contrivances enable the supply of fuel to be varied in this apparatus, the one consisting in the alteration of the size of the apertures by changing the position of the slides *M M M*, and the other in the three drums *T T T*, of different diameters, which, when adjusted, communicate different velocities to the grooved cylinders *H H*.

These cylinders revolve about 45 times per minute, and discharge about 33 lbs. of coal per hour into the grate. The power required by the machine is estimated at 6-horse power, and it is therefore worked with about 5½ lbs. of coal per horse power per hour.

The most perfect consumption of smoke is effected in the travelling grates, which were first invented, and in their most perfect form, by Mr. J. G. Bodmer. Economy of fuel and the consumption of smoke are the great advantages of these grates. Although the expensive nature of the original invention precluded their general adoption, several modifications on the same principle were successfully introduced by Jukes and Haseldine, both of whose grates were worked by Price's Patent Candle Company, at their Vauxhall Works, and found to consume inferior coal without smoke with considerable advantage.

The annexed drawings show the application of Bodmer's screw-grate to a

common cylindrical boiler, set in brick-work. The man-hole, safety valve, &c., are omitted, as these may be made in the ordinary manner.

Fig. 359 is a front view of the brick-work and grate. Fig. 360, a longitudinal section; Fig. 361, transverse section; and Fig. 362, a horizontal section above the grate-bars. 1 is the brick-work; 2 and 3, cast-iron plates, which rest upon the brick-work 1, and support that portion of the brick-work above, which constitutes the hearth and the bottom part of the flues, and which is best seen in Fig. 361. The bridge 4 (see Fig. 360) is here made of wrought-iron plates, and so constructed as to be kept cool by a stream of water from above, in the usual manner, and to be easily removed when burnt. The brickwork behind the bridge is hollowed out and arched over as usual (see Fig. 362). The bottom plate 5, is fixed to a stone, or to the flag of the floor, and supports the standards or frames 6 and 7, to which the screw-bearings 8 and 9 are cast, and to which the grate rails 10 and 11 are fixed, which support the grate-bars 12. The return rails 13 and 14, upon which the grate-bars marked 15, return, are fixed to the same standards as the rails above. The grate-rails 10 and 11 are cast in the shape of an angular plate, and strengthened by brackets, for the purpose of making them strong enough to support the grate-bars and the coal. The bottom plate 16, in front, is similar to that already described; but the

Fig. 359.

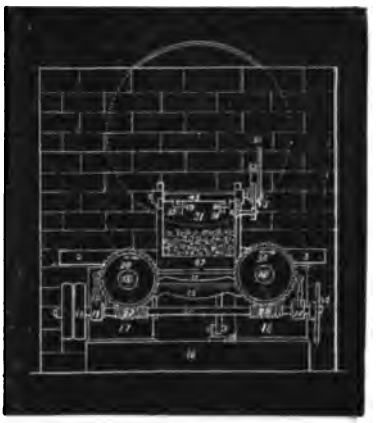
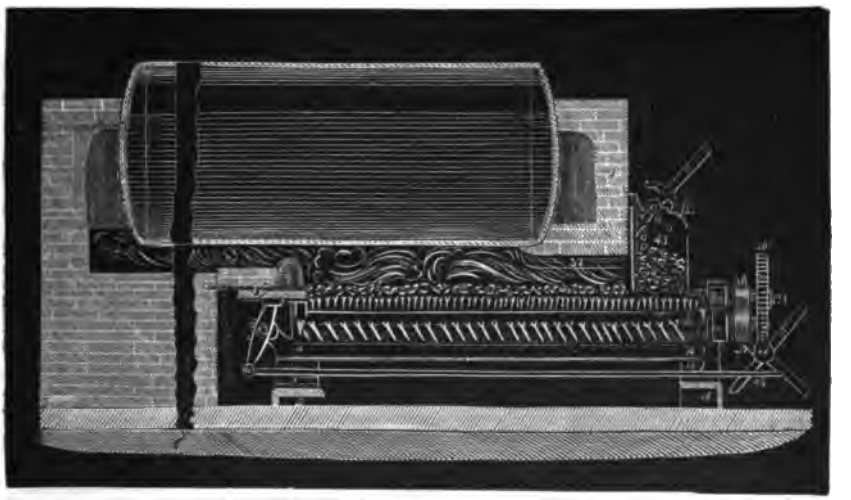


Fig. 360.



standards 17 and 18 are so arranged as to carry the bearings 19 and 20, in which the worm-shaft 21 revolves; and instead of having the screw-bearings 22 and 23 cast to it, they are fixed by bolts, so that they can be easily removed. The grate-screw 25 has a left-handed thread, and the grate-screw 24 a right-handed thread, and they are so constructed as to keep the

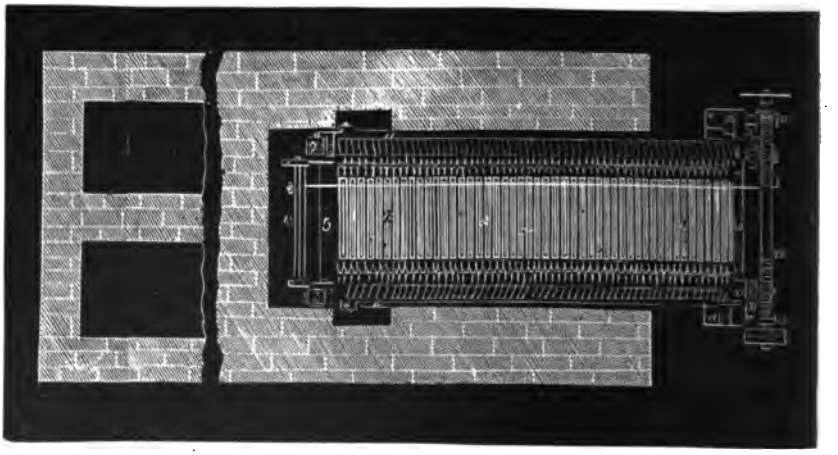
grate-bars close together until they arrive at *a* (see Fig. 360), then the space between them begins to increase, so that at *b* they assume their full distance, which is the same until they arrive at *c*, when they begin quickly to approach again, so that at the bridge they are only about one-third of their former space apart.

The screws are cut in such a manner as not only to keep the grate-bars at those described distances, but also to give them an increasing rocking motion, which begins at *d*, increases as far as *e*, remains the same as far as *f*, and dies away into a regular screw-thread towards the end of the screw. It is clearly shown in Fig. 362 that the rocking motion of the bars is accomplished by what is vulgarly called a drunken screw-thread, and that the grate-bars are kept close together in that part of the grate in which the hopper is placed, merely by having the screws cut to a proportionately finer pitch; and this is simply for the purpose of preventing the fine coals from dropping through the grate-bars.

Fig. 361.

Suppose the coal to be put into the hopper, as shown in Fig. 360, and the grate-screws, between which the grate-bars are placed separately, to be put in motion by a strap working on a pulley 26, which is fixed on the worm-shaft 21. The right-handed worm 27 (see Fig. 359) gears into the worm-wheel 28, fixed upon the left-handed screw 25; and the left-handed worm 29 gears into the worm-wheel 30,

Fig. 362.



fixed to the end of the right-handed screw 24. It is thus evident, that when the worm shaft causes the worm-wheels 28 and 30 to move in the direction of the arrows (see Fig. 359), the grate-bars will advance, and carry as much coal into the furnace as will be admitted by the position of the slide-door 31.

As the coals will be ignited by degrees as they make their appearance

under the brick-arch 32, it is evident that the gas must generate slowly and gradually, and pass in a regular and uninterrupted stream over the ignited surface of the whole grate. Moreover, as the gases are generated near the hopper, they will have to pass over the whole surface of the ignited fuel, and thus become heated for ignition, and consequently consumed before they arrive at the bridge. Sufficient air can also be admitted, either at both ends of the grate-bars, or by a few tubes through the brick-work; and thus not only is the smoke consumed, but the effective heating power derived from the coal is increased to a very great extent.

The rocking of the bars is made to begin at a place marked *d*, where the coals are already beginning to coke, and the danger of working the small coals through the grate-bars is removed; the grate-bars are made to perform an equal and strong rocking motion from that part of the grate marked *e*, to that part of the grate marked *f*, by means of which the coals are kept in constant motion, the ashes removed from them, the contact of the coals changed, the grate-bars prevented from clinkering, and a clear and brisk fire kept up without that extraordinary draught which is required in other grates.

To prevent the heat becoming too great at the bridge, the spaces between the grate-bars, from *f* to the bridge, are gradually diminished, thus reducing the admission of air; and the rocking is made to cease in that part of the screw in which the hindmost grate-bar is caused to drop, by means of the tappets 33 and 34, into the return-screws 35 and 36, which are placed directly under the grate-screws. The return-screws are caused to revolve by means of the pinions 37 and 38, placed behind the worm-wheels 28 and 30, and the pinions 39 and 40, fixed to the ends of the return-screws; and as the screws thus revolve in opposite directions and exactly at the same speed, it is evident that the thread of the return-screws will receive the grate-bar (which is forced down by the tappets) in its thread, and carry it again to the other end of the screw, where it is lifted up by the tappets 41 and 42 of exactly the same construction as the tappets 33 and 34, is placed into the thread of the top screw, and forms again a portion of the grate. The thread of the return-screw is of double the pitch of the grate-screw, for the purpose of allowing the ashes to descend and the air to ascend. It is quite clear that by this arrangement any defective grate-bar can be taken out, and a new one put in its place; and that in fact the whole set of grate-bars can be exchanged without the slightest interruption of the combustion. The grate-bars which form the grate are supported by the rails 10 and 11, as already explained, and return upon the rails 13 and 14. To the ends of the rails 13 and 14 a fork is cast, by which the scraper-shaft 43 is supported, the arms of which take into an iron slide 44, to which the wrought-iron scraper-plate 45 is fixed. It is under this plate that the grate-bars descend; and for the purpose of getting rid of the clinkers, &c., which of course are all carried to the bridge, the plate or slide 44 is drawn back by means of the bar 46, and thus the clinkers are allowed to drop. The hopper 47 consists of cast- or wrought-iron plates, and may either be left open at the back, or closed by a sheet-iron plate, which can easily be removed for the purpose of having access to the grate; and the slide-door 31, which regulates the depth of the coal, is worked by means of the shaft 48, the arms 49 of which take into the snugs 50 and the lever 51; and the slide-door is held in its place by the toothed segment 52, and click 53.

The cross 54 on the worm-shaft 21 is simply for the purpose of moving the grate by hand, which in most cases is required when a fresh fire is put in; this is done in the usual manner, except that the coals towards the bridge are laid considerably thinner than nearer the hopper.

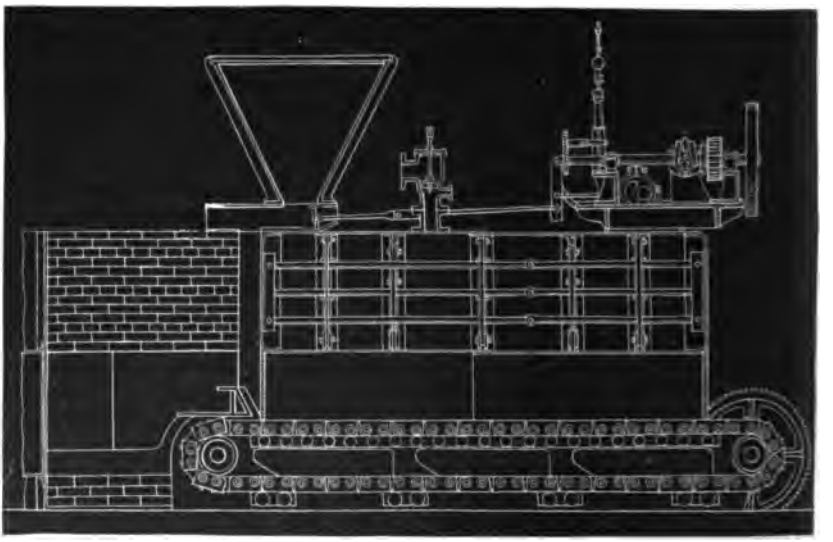
As very little power is required to work this grate, a small working

cylinder of a few inches only in diameter, according to the pressure of the steam, can be placed upon the top of the boiler to work the grate and the feed-pump, which will be convenient in such places where boilers are used for other purposes than steam engines. By a simple arrangement and a pair of cone-pulleys, the heating-power of the grate can be increased or diminished as the consumption of steam and the pressure may require, and the grate can be made self-acting in every respect.

FIG. 363.

This grate is superior to Mr. Bodmer's drum-grate and chain-grate, the latter of which was brought into public notice by Mr. Juckes, and appeared to give great satisfaction with respect to economy and regularity in the combustion of the gases; but the screw-grate is preferable, on account of its simplicity, the facility of repairs, change of grate-bars, and more perfect and economical combustion. A modification of the Bodmer grate was introduced by Mr. Joseph Townsend (see Figs. 363, 364) into his

FIG. 364.

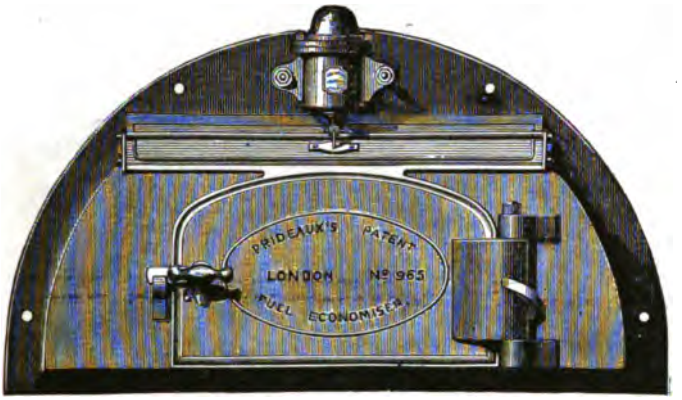


Crawford Street Chemical Works at Glasgow, and worked there with satisfactory results.

Mr. Prideaux, conceiving that expensive and complicated arrangements

like the grate just described would never force themselves into general use, endeavoured to adjust the supply of air to boiler-fires in a manner to meet the fluctuating demands of the fuel by a self-acting valve applied to the fire-doors of the furnace, Figs. 365–367. This invention is extremely simple in principle, and has been most favourably reported on by naval officers who have witnessed its effects in marine-boiler stoking, where it not only prevented

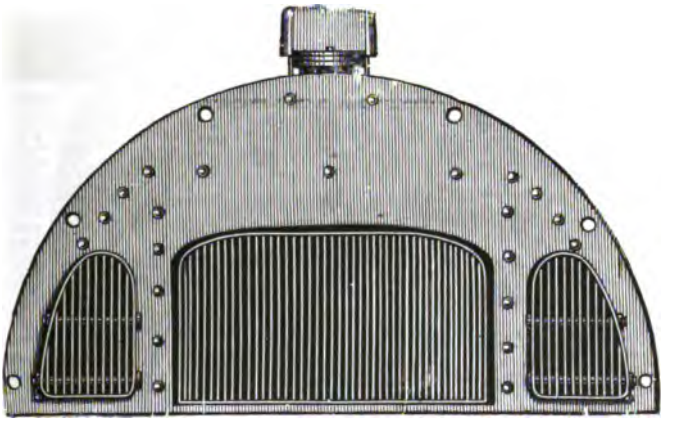
FIG. 365.



Front view.

smoke and consequently increased the effective value of the fuel, but likewise diminished the excessive and highly injurious temperature of the furnace-room or stoke-hold. No change is required in the construction of the grate, and the existing arrangements for coaling remain untouched; but a hollow or double fire-door is substituted for the single one generally used, the inner

FIG. 366.

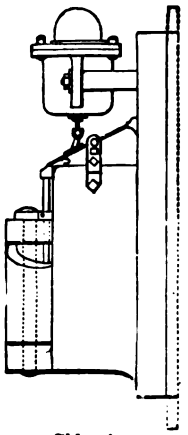


Back view, opening on interior of furnace.

plate of which is pierced with numerous small holes, through which the air, warmed by contact with the hot metal, obtains access to the furnace and is subdivided into minute jets which, coming into contact with the products of combustion, enable them to be completely consumed. The supply of air is regulated by a sliding valve in the face of the outer door; this valve is

attached to a lever, which is raised as soon as fresh fuel is thrown upon the fire, and falls gradually by its own weight, slowly closing the valve, and thus diminishing the supply of air with the diminishing requirements of the fuel. The area of the valve, and the time occupied in closing, must be regulated according to the nature of the fuel and other circumstances, which may vary in each particular case. It is the supply of hot air just at the time when it is required, and in the proper quantity, that constitutes the merit of this invention, while the double

Fig. 367.



Side view.

Fig. 368.

door prevents the radiation and consequent loss of heat. The same result has been aimed at in a multitude of inventions for regulating the supply of air by furnace and ash-pit doors. A very simple door (Fig. 368), which swings both ways, has been invented by W. A. Martin for this end. Its application to a steam boiler is shown in Fig. 369.

Fig. 369.

There has been considerable development in the construction and improvement of mechanical stokers since the year 1813, when one of the earliest attempts was made.

The following description of some of the most successful of these stokers is extracted from an excellent paper by Mr. J. W. Pearse ("Trans. Society of Engineers," vol. 1877) on this subject:*—

"In the year 1822, Mr. John Stanley invented a stoker with a pair of fluted horizontal rollers for crushing the coal as it descended from a hopper in front of the boiler, at the same time equalizing the supply. Below the rollers, a three-armed fan was fixed, revolving on a horizontal axis, for the purpose of projecting the coal into the furnace. In 1834, Mr. Stanley, with the co-operation of Mr. John Walmsley, substituted indented for fluted rollers, and made the fan to revolve on a vertical instead of a horizontal axis. He also arranged the fire-bars so as to rock by means of gear connected with the stoker, and caused the steam in the boiler to act on a float in a siphon tube for stopping the feed when a certain pressure was attained. In 1838, Mr. John Juckes patented an arrangement of screw rams, by which successive charges of fuel were forced into tubes, where the coal was distilled before being discharged into the furnace. In 1839, he devised a narrow movable platform in the middle of the fire-bars, and hinged at the back end. On a fresh charge being propelled by a plunger on to this platform, it was forced up to the level of the fire-bars, both actions being performed by levers. In 1841 Mr. Juckes patented the invention with which his name is more particularly associated—viz., an endless chain of fire-bars, supported at each end by rollers, which are carried on trucks. As the chain passes under the boiler, it draws from a hopper its supply of coal, which is regulated by a door sliding vertically. In the next year, he somewhat modified this idea and constructed his circular grate, made to revolve by means of a rack fixed to the circumference, and driven by a pinion. A portion of the grate is always outside the furnace, when the bars, which are pivoted at one end, fall down in succession to allow of the disengagement of the clinker, and are then raised again before entering the furnace. The fuel is drawn along much in the same way as in the previous arrangement.

"In 1863, Messrs. Wilson and Smith caused their fire-bars, which were of the ordinary shape or nearly so, to travel backwards from the front of the furnace, so as to carry towards the bridge the fuel fed from a hopper provided with a regulating damper; the bars then moved backwards, either singly or in pairs, the motions being given by two drums, fitted with projecting arms, placed underneath the bars at the front end, and driven by any suitable means.

"In 1867, Mr. Thomas Vicars, Mr. Thomas Vicars, jun., and the same Mr. Smith, patented some improvements on the preceding invention. Between the Wilson and Smith fire-bars, they placed others of shorter length moving backwards and forwards to a less extent than the travel of the former, from which they received motion. Again, instead of passing all the fuel from the front end under the furnace door, they supplied the whole or part of it from a hopper, situated at a higher level, and from which tubes descended to the grate. In some cases, part of the supply was led by a tube through the boiler itself, so as to deliver about midway between the front end and the bridge.

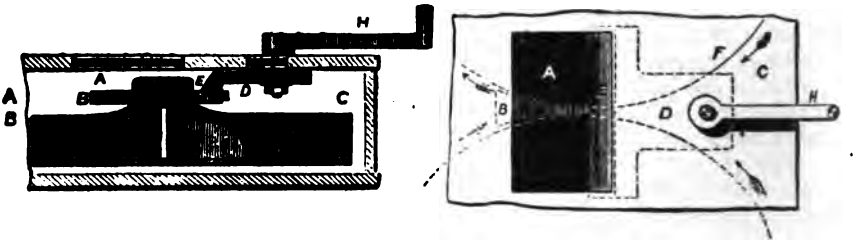
"In 1870, Mr. Dillwyn Smith filed his specification. In the stoker associated with his name, the coal is allowed to fall from a hopper in front of the boiler into a horizontal cylindrical receptacle, in which works a helical screw for giving the feed. In the case of a double-flued boiler, the screw is made right- and left-handed, the middle being placed just under the centre of the hopper; and from the middle the diameter of the screw gradually increases until, at the ends, it becomes almost as large as that of the casing. At the ends of the screw shaft, and outside the screw, are projections for

* See also "Jour. Soc. Chem. Ind.," 1883, vol. ii. p. 71.

more evenly distributing the coal as delivered by the screw. The pieces of coal are caught in falling by the vanes of a pair of fans, revolving towards each other in a horizontal plane, and are by them projected on to the furnace. As the pieces which are struck by the ends of the vanes are projected farthest into the furnace for a given size, and as the size of the pieces varies, it follows that an even distribution of fuel is effected over the whole area. The fan-shafts are driven by belts from a separate vertical shaft, actuated by a donkey engine or any available power; and the shaft of the feed-screw is driven by a worm and worm-wheel put in motion by another vertical shaft worked by a strap off one of the fan-shafts, a pair of cone-pulleys and a rod and lever serving to change the speed as may be required.

"In the same year—1870—some improvements on the Dillwyn Smith stoker were made by Mr. George Frederick Deacon. It sometimes happened that, when large coal was used, some of the pieces were not sufficiently reduced by the screw in one of their rectangular directions. To obviate this, a second but smaller thread was introduced between the main thread, and, like it, gradually increasing in size. It was also found that coal-dust sometimes accumulated between the disc of the fan and the bottom of the casing; this was counteracted by casting a narrow spiral feather on the bottom of the disc, and making some holes to admit the air, so that a sufficient draught was created to prevent the accumulation. At the same time, the fan shafts were reduced in height, chiefly to diminish the friction of the lower foot-

FIG. 370.



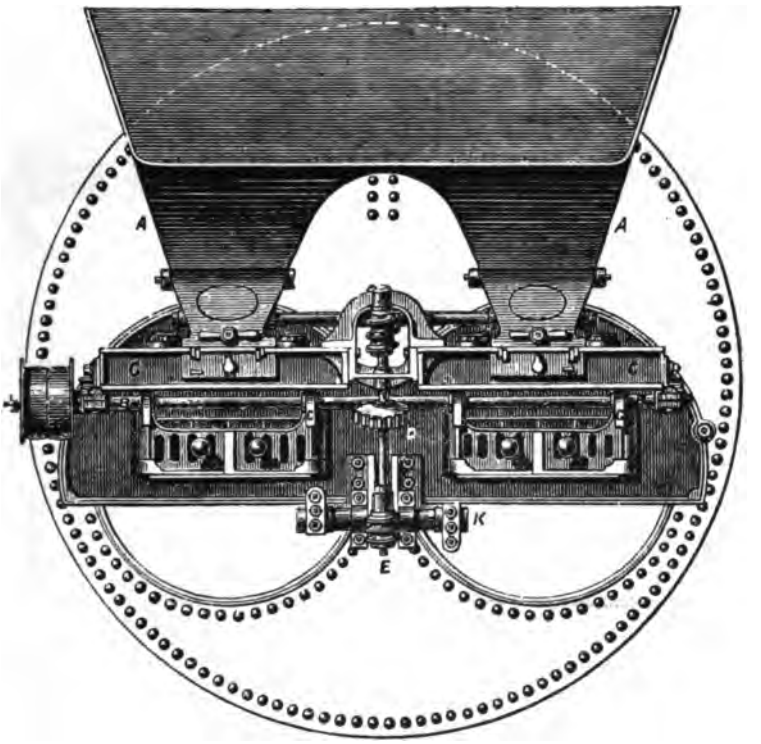
step, which for this reason, as well as on account of the conducted heat from the furnaces, it was sometimes found difficult to keep cool. A non-conducting substance was also introduced between the foot-step and the under side of the fan-case. One of the fan-shafts was, however, retained at its former height to serve for driving the others, the pulleys of which were kept as near the fans as the screw casing permitted. Each of the shafts had two bearings in a single bracket above the fan; and the step was sometimes dispensed with altogether by forming a collar on the upper ends of the shafts. Subsequently, the fan-shafts were driven by toothed or friction wheels, enclosed in a chamber immediately below the fan-case, thus dispensing with all but one belt, because they were found to be deteriorated by the heat of the fire if the machine was kept standing for any length of time. Perhaps the most important addition made by Mr. Deacon was his deflector for causing all the particles of fuel delivered by the screw to fall upon the fans. This consists of two castings bolted together, shown both in elevation and plan at Fig. 370, where *A* is the aperture through which the fuel falls, and *F F* the two fans. The particles are prevented from falling between the fans on the hinder side of their centre line by the inclined edge *E* of the plate *D*, and at the front side by the part *B*, which has a triangular section and curved base. The handle *H*, the stud of which passes through the slot *S* in the fan-casing *C*, allows the deflector to be moved both inwards and

outwards, as well as in a radial direction, until that position is found in which the most uniform delivery is secured.

"The Henderson stoker, which incorporated Mr. Deacon's additions, contains still further improvements on that invented by Mr. Dillwyn Smith: and the two interests are now merged in the Mechanical Stoker Company. Additions and modifications were patented by Mr. Thomas Henderson in 1872, 1874, 1875, and so late as the end of last year. Instead, however, of following these successive changes one by one, it will perhaps be better to describe the Henderson stoker as it now exists, with the latest improvements introduced.

"Fig. 371 shows a front elevation of the stoker as applied to a Lancashire boiler; Fig. 372 is a side view, partly in section; and Fig. 373 is a horizontal

FIG. 371.



section, showing the fire bars. The coal contained in the hopper *A* is fed down the two divisions, one in front of each flue, by means of a roller, which is modified in form according as it has to crush coal, or merely regulate the supply of slack. The particles, as they fall, are caught by the arms of two fans contained in the fan-case *C*, revolving towards each other in a horizontal plane, and are by them projected into the furnace, being distributed equally over the whole surface as in the Dillwyn Smith arrangement. The great improvement consists in the compact arrangement of parts, and the direct manner in which they are driven. Thus, a horizontal shaft *B*, made to revolve by a belt and pulleys, or in any other convenient manner, is carried by bearings immediately under the fan-case, and, by means of a worm in the centre, turns a worm-wheel *D* on a nearly vertical shaft *E*.

Fig. 372.

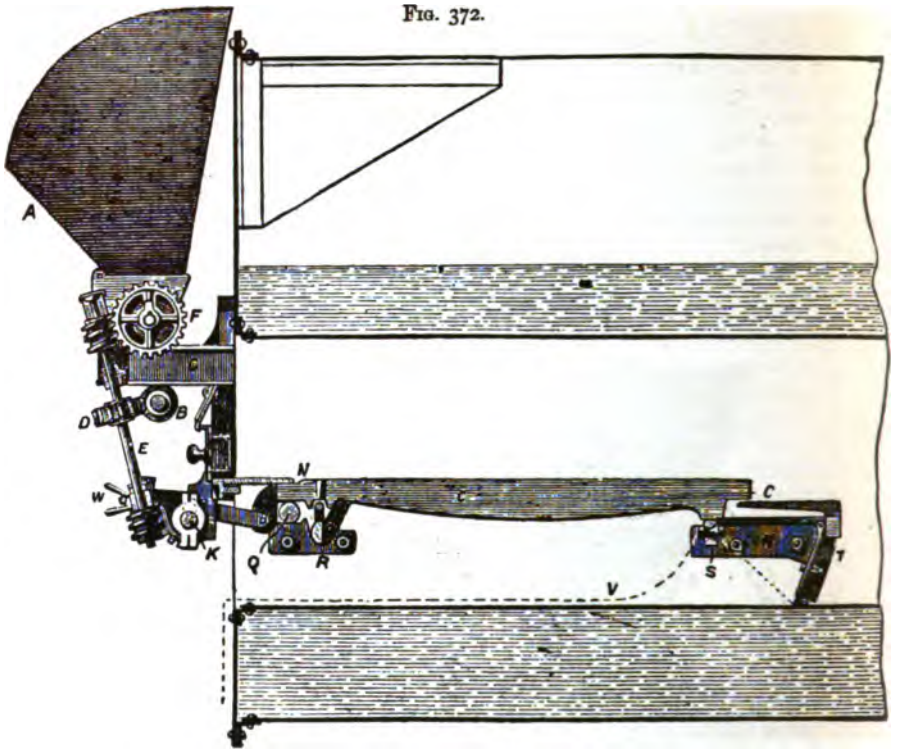
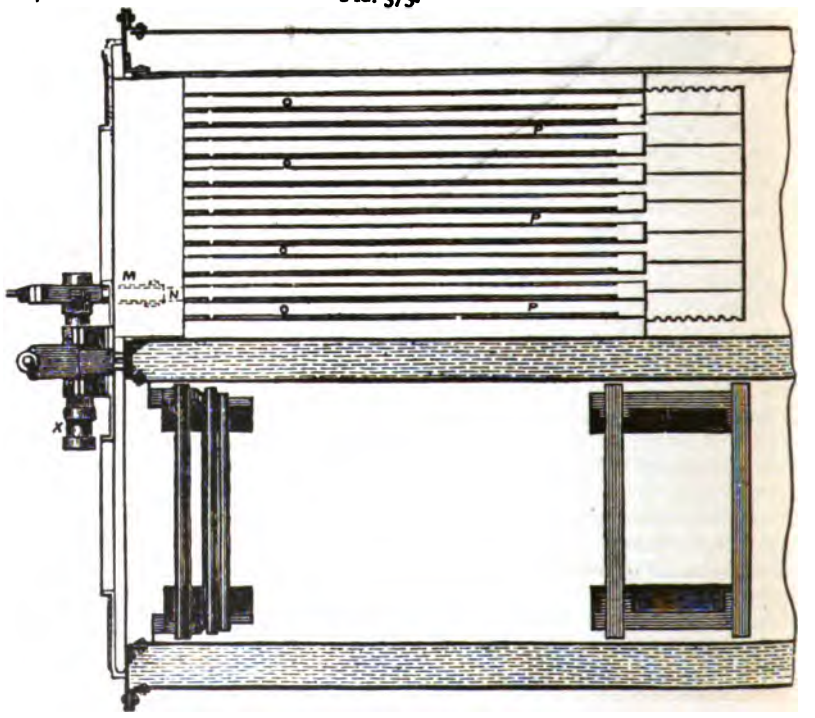


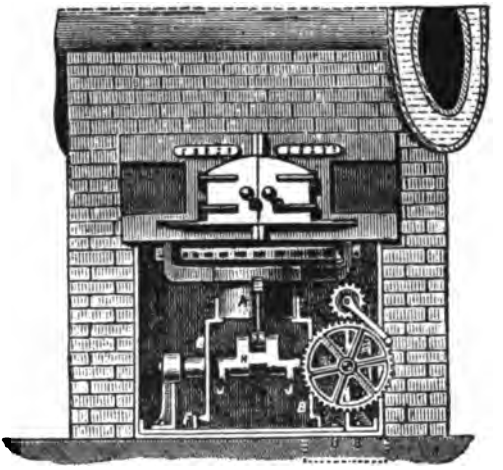
Fig. 373.



This shaft carries a worm at its upper end, which gears with a worm-wheel *F*, keyed on the feed shaft, while it has another worm at its lower end for moving the fire-bars. The fans are driven direct by friction pulleys *G G*, on the horizontal shaft, working against a ring of leather, for preventing rattle, fixed to their hollow under-side. The fans, therefore, revolve at the rate they are speeded—about 200 a minute—but the feed is regulated by turning the hand screws *I I*, which push in or draw out the front plate of the hopper, which is provided, if necessary, with an indented steel plate for facilitating the crushing of the coal. Sight holes are made in the fan-cases for affording means to ascertain that the fans are properly working; and part of the bottom plate of the fan-case is constructed so as to be easily removable for taking out a fan in case of need. Sliding ventilators for regulating the admission of air, are also provided in the furnace doors, as shown in the front elevation. The two outside fire-bars remain stationary, but the others have a motion imparted to them by the crank of the short horizontal shaft *K*, links *M*, and projecting or connecting bar *N*. Every other fire-bar, *O O*, slides on the roller, *Q*, while the rest, *P P*, carried on the rocker *R*, and cross-bearer *S*, are, owing to the cranked shape of the rocker, made to rise and fall. The ashes and clinker are thus carried in one direction, according to the setting of the cranks. In the arrangement shown in Figs. 372 and 373, they are carried to the back end of the flue, on to a kind of dead plate formed by the ends of the lifting bars, which are continued beyond the sliding bars; they gradually fall into the ashpit at the back, whence they are removed periodically by means of the hanging door *T*, worked by the chain *V*, from the front of the boiler. By this arrangement, not only is the supply of fuel automatic and continuous, but there is also an automatic stirring of the fire and cleansing of the fire-bars continually going on. According to the nature of the fuel and the demand on the boiler, the amount of rise and travel of the bars can be regulated by turning the hand screw *W*. At the same time, this double action of each alternate bar lifting and sliding keeps the interstices between them clear for the free admission of the air necessary for combustion.

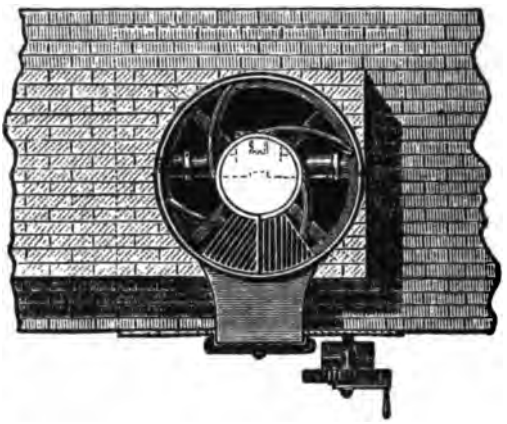
"All the foregoing mechanical arrangements for supplying fuel to furnaces appear to have been designed in imitation of the supposed perfection of hand-stoking—that is, the even distribution of a thin layer of coal over the whole surface of the fire, and as lightly as possible, so as to admit plenty of air for effecting the combustion. In the Frisbie feeder, however, a different principle has been adopted—that advocated by Dr. Arnott for domestic fire-places. This consists in supplying fresh fuel from below, and this, on being subjected to the heat of the incandescent mass above, evolves its gas to be consumed on rising through the fire. The other arrangements are for quick combustion; this one is for slow combustion. In those the feed is continuous, whilst in this it is intermittent; but the evil of admitting

Fig. 374.



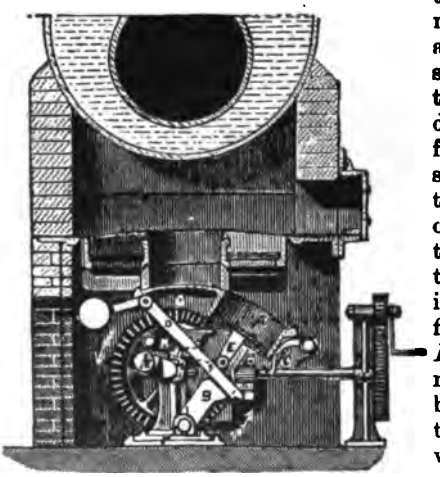
a volume of cold air on the top of the fire is avoided in this case as in the others. In 1868, Mr. Myron Frisbie, of New York, without claiming to originate the idea of feeding fuel from below, patented an arrangement whereby coal was thrust up underneath, and in the middle of the fire, and several of his machines are still at work, doing very good service. In 1875, Mr. James Millward Holmes and Mr. Walker, of Birmingham, introduced into this feeder some improvements, which chiefly consist in substituting gear for the direct action of a lever, whilst at the same time the whole machine is simplified.

Fig. 375.



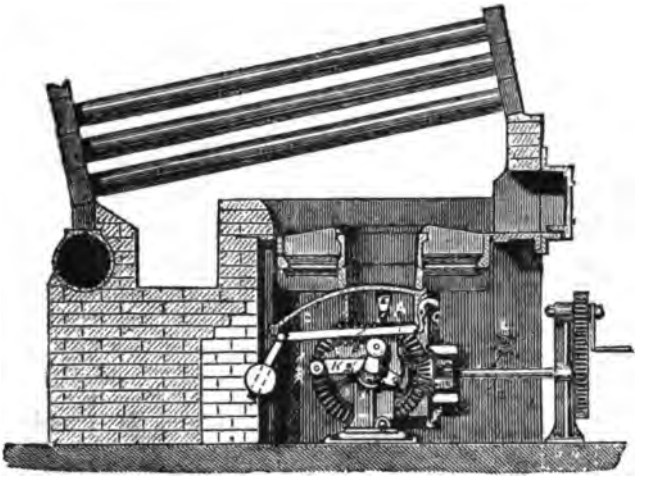
"Fig. 374 is an elevation of the improved Frisbie feeder as applied to a Cornish boiler; Fig. 375 is a plan of the fire-grate; Fig. 376 a vertical section, showing the fuel-box in the position for receiving a supply of coal; and Fig. 377 shows the position it assumes while the charge is being thrust into the furnace from below. In Fig. 377, the feeder is shown applied to a Root's tubular boiler. In place of the usual straight fire-bars, there is a central circular aperture surrounded by segmental gratings (shown best in the plan, Fig. 375), which are easily removable, whilst the whole annular arrangement of grate runs on friction rollers like a turn-table, and may be moved round by means of a crow-bar inserted in the holes shown at Fig. 374. Underneath the central aperture is the cylindrical fuel-box *A*, mounted on forked side-frames *B B*, which swing on pivots *F F* attached to the base-plate along the centre line of the fuel-box. Cast in one with this fuel box is the apron *C* for retaining the coal when the box is in its inclined position ready for being filled; and jointed to it is the lever *D*, by the intervention of which the rod *E*, attached to the movable bottom of the fuel-box, is raised by the crank of the shaft to be afterwards described. *A*, *B*, *C*, *D*, and *E* swing together on the pivots *F F*; but the movable bottom of *A* is at the same time capable of rising and falling, being retained in its highest position by the catch *G* engaging with the nose of the lever *D*. The crank of the shaft *H*, mounted on bearings, also arranged along the central line of the fuel-box, carries a friction roller *I* which acts in its rotation upon the lever *D*, and consequently raises the movable bottom of the box. This shaft has also another pair of arms *J J* provided with pins

Fig. 376.



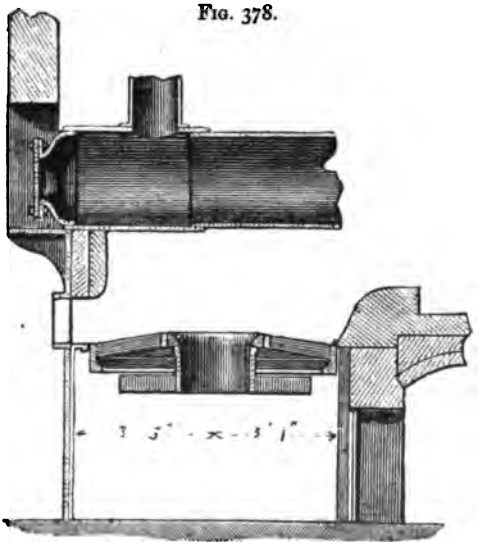
which take into notches in the links *K K* jointed to the forked plates *B B*, and thus alter their position from inclined to vertical, and *vice versâ*. The shaft is moved by the bevel gear and winch, either direct in a small machine,

Fig. 377.



or with spur wheel and pinion in a larger one, as shown in the vertical sections. Assuming that the fuel-box is filled with coal in its inclined position, the winch is turned so as to move the crank-shaft in the direction of the arrows in Fig. 376. The arms *J J*, by means of the links *K K*, draw the forked plates and fuel-box underneath the central aperture, when the links rest upon the shaft, locking the box in its vertical position. As the crank continues to revolve in the same direction, the pins leave the notches in the links; and the friction roller *I* comes into contact with the lever *D*, and raises the movable bottom of the fuel-box, thus forcing the coal upwards into the fire. The bottom is held in this position by the nose of the lever *D* engaging with the catch *G*. The winch is now turned the reverse way, which causes the shaft to revolve in the direction shown by the arrows in Fig. 377. The pins again engage in the links *K K*, thus pulling over into an inclined position the forked plates and fuel-box, which latter is followed up by the apron *C* for the purpose of retaining the coal in the fire-grate. As soon as the catch *G* strikes the bar *L*, it releases the lever *D*, and thus allows the movable bottom to fall to its first position, ready for another charge of fuel. Each

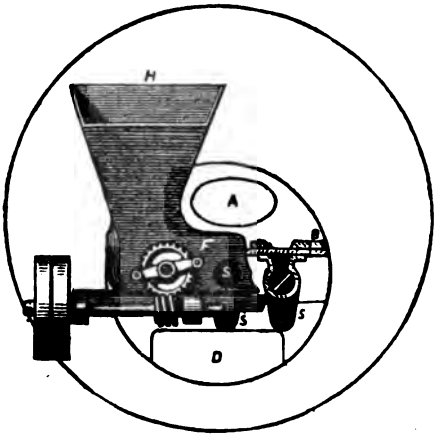
Fig. 378.



Longitudinal section.

fresh charge displaces that previously inserted, and thus has the effect of moving the whole fire. This action breaks up the cinder, and gradually carries any hard clinker that may have formed to the circumference of the grate, where it is removed at intervals by bringing in succession each part of the segmental gratings before the furnace door by means of a crow-bar.

Fig. 379.

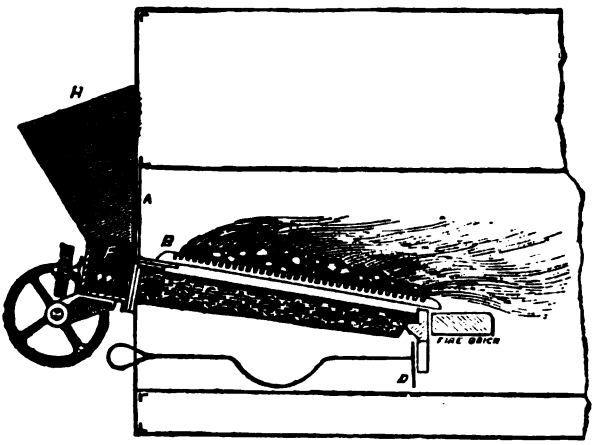


Front elevation, partly in section.

"It is evident that this arrangement is not applicable to the flues of Cornish or Lancashire boilers as they are usually fired; but the Frisbie feeder has been applied with success to these boilers, either in the middle of their length, as shown at Fig. 374, or at one end, in a kind of combustion chamber made of fire-brick, communicating directly with the internal flue. There also seems now to be a reaction in some quarters in favour of externally fired boilers, especially that class in which two or more large horizontal water-tubes are connected by smaller vertical tubes, as shown with the Frisbie feeder attached, in sketch, Fig. 378.

"The 'Helix' fire-feeder, devised by Mr. Holroyd Smith, appears to combine, in a modified form, the two principles before mentioned—that is to say, the fuel is fed from below, and at the same time the feed is continuous. Its application differs from that of the Frisbie feeder in being more suitable for an internally fired boiler, for which, in fact, it was specially designed. In this appliance, two or more of the ordinary straight fire-bars are replaced by a trough, in communication, at the bottom, with a tapering case of cylindrical section, in which works an Archimedean screw of modified form. The fuel contained in a hopper, placed in front of the boiler, is thus absolutely screwed into the fire underneath the incandescent coal, so that the gas is extracted by the heat, and burnt as evolved. The air necessary for combustion makes its way between the interstices of the bars, which are serrated on their upper edges for facilitating its distribution through the fire.

Fig. 380.

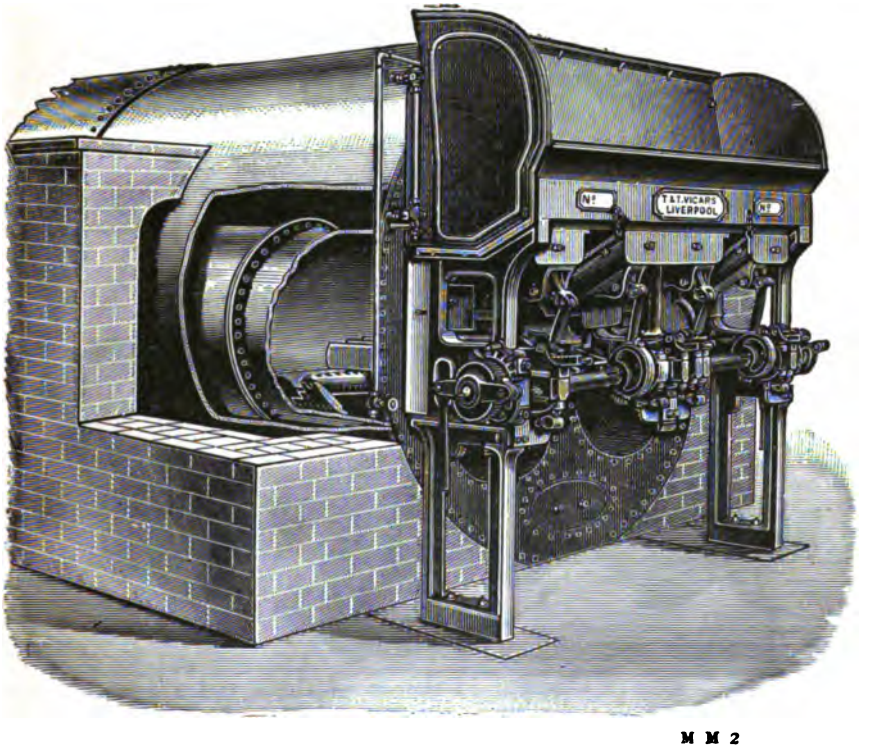


Side elevation, partly in section.

"Fig. 379 shows a front view of a Cornish boiler fitted with this arrangement, part of which is in section; and Fig. 380 shows a longitudinal section of the boiler, with the 'Helix' partly in section and partly in elevation. The hopper *H* is in communication with the feed-trough *F*, which is placed across the front of the flue, and communicates in turn with two or more screw cases, according to the size of the boiler. In the diagrams, three of these cases are shown, containing the screws *S S S*. As this screw is of uniform pitch but of gradually decreasing diameter, suitably calculated, it delivers the fuel evenly throughout the whole length of fire-bars *B B*; and the coal must be forced upwards through the longitudinal aperture, as that is the only outlet. Any large lumps of coal are crushed by the screw before being passed on. The cinders fall over the fire-brick bridge, and are removed once a day by withdrawing the damper *D*. *A* is an ordinary fire-door for the inspection of the fire, for banking it up, or for use in hand firing, in case of a break down to the engine driving the feed gear or from any other cause."

Another mechanical stoker which has distinct features is that of Messrs. Haworth and Horsfall, called the Todmorden stoker. It has the usual hopper in front of the boiler, but between the hopper and the boiler front is a coking chamber built of fire-brick. Two sets of short bars advancing and receding alternately convey the coal through this chamber and on to a set of fixed water-tube bars in the boiler. These bars are in communication with the water in the boiler. They are semi-oval in shape, and are tested to 200 lbs. pressure per square inch. The fuel on these bars is moved towards the back of the fire by toothed rakes or scalers which rise up between the bars, cut into the fuel, and move it on about 2 inches. This takes place at

FIG. 381.



intervals of a minute and a half and keeps the fuel broken up for the passage of air through it.

The stoker of Messrs. T. & T. Vicars (Fig. 381) is the parent of a number of others worked on the same principle. This is the principle of moving

Fig. 382.

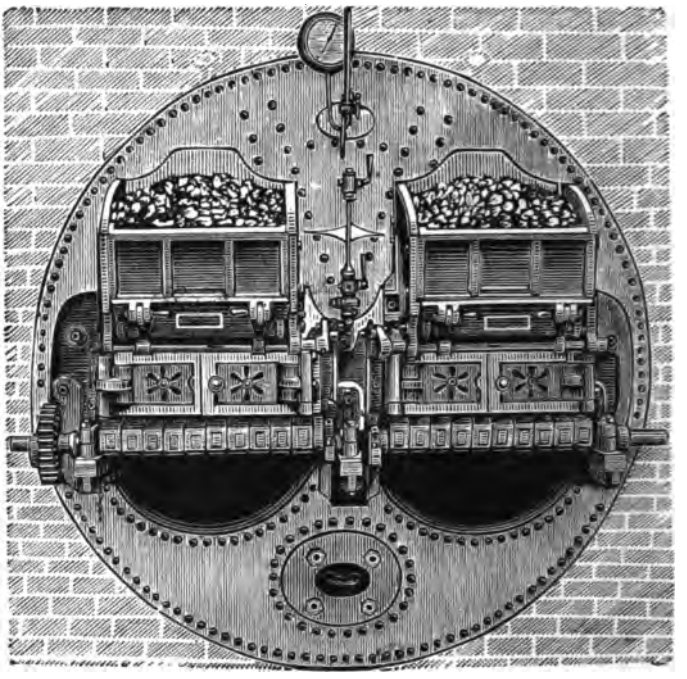
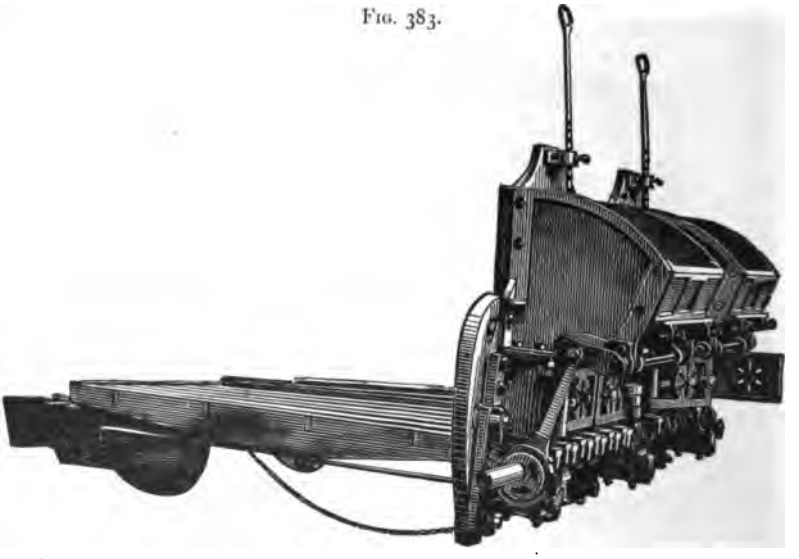


Fig. 383.



fire-bars. They are arranged in groups of three, and are periodically pushed forward *en masse*, carrying the fuel with them, but are drawn back

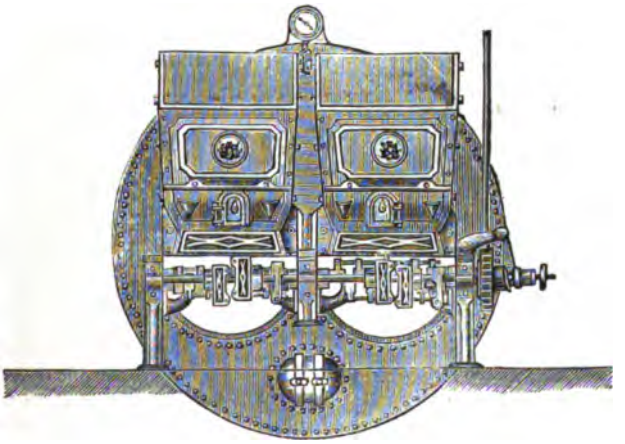
one by one, a bar of each third group being moved successively. A cam shaft running across the front of the furnace gives the necessary motion to the bars.

McDougall's mechanical stoker (Figs. 382–384) works on the same prin-

Fig. 384.

ciple as Vicars' with some slight modifications; and the same may be said of Auld's stoker (Figs. 385, 386), which, like McDougall's, has been successfully applied to a number of boilers.

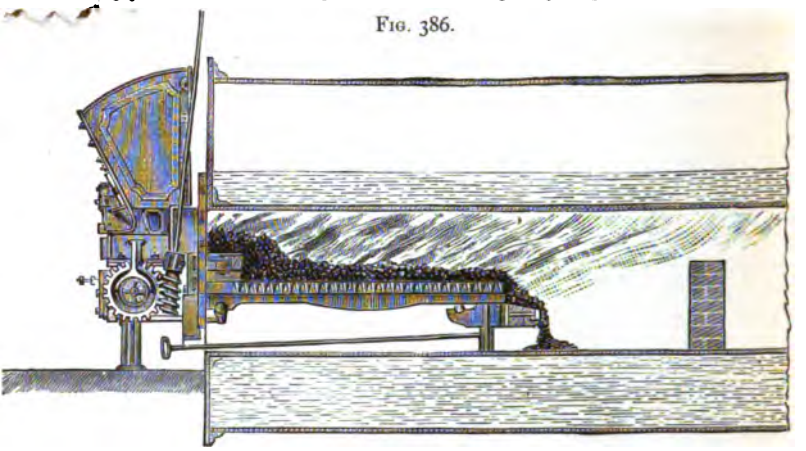
Fig. 385.



Proctor's mechanical stoker spreads a thin layer of fuel over the surface of the grate by means of the sharp movement or blow of a vane or rocking "shovel" of sheet-iron, which works in a chamber into which dross is fed from a hopper above. The movement is produced by a cam on a slowly revolving shaft which gradually draws the vane back, at the same time

putting a spiral spring (which is attached to a lever on its axis) in tension. On the cam releasing the vane, the spring imparts a quick return

Fig. 386.



forward motion to it, when it strikes the coal which has filled its chamber during its backward move, and projects the pieces into the furnace more or less according to their size and weight.

The following figures* giving comparative results with hand firing and mechanical stoking will be found of interest:—

	Lbs. Fuel supplied per Hour.	Water evaporated per lb. of Fuel.	Gallons of Water per Hour evaporated.	Exit Gases.	
				CO_2.	O.
Hand firing . .	419	6.417	269	7.53	12.01
Stoker No. 1 . .	323	7.274	235	6.91	12.03
" " 2 . .	419	7.076	296	11.58	6.44
" " 3 . .	523	6.898	361	8.17	9.55
" " 4 . .	617	5.856	361	10.04	9.20

In giving these results, Mr. G. E. Davis remarks that it should be mentioned that mechanical stokers are not smokeless when driven too hard.

Fig. 387.

This description does not exhaust the list of mechanical stokers which are manufactured, but sufficiently shows the general principles governing their construction and use.

Anthracite is much more difficult to burn under boilers than so-called bituminous coal; a much thicker stratum must be kept at a red heat, or the fire is liable to be extinguished; many varieties will not bear stoking without falling to a fine powder, which then arrests the draught; others produce a great amount of clinker. Those which have but little residue and fall to pieces, like the majority of the Welsh and American anthracites, may be burnt in the manner proposed by M. Player, and shown at Fig. 387. A fixed grate, with

* "Jour. Soc. Chem. Ind.," 1883, vol. ii. p. 71.

straight fire-bars, is fed from a hopper kept constantly filled with anthracite; the fuel then forms a cone, from the end of the hopper to the grate, and descends as it is consumed, on the principle of the ancient "athanor." There is no door to the grate, the entire quantity of air being supplied from below the bars: the fuel, being heated as it descends the hopper, does not cool the fire, as is the case when it is introduced cold through a fire-door, and the decrepitation, if there be any, will occur before it reaches the grate. With some varieties, it would be necessary to supply some means of clearing the grate-bars of clinker. In burning fuel of this description, an accurate regulation of the draught is very necessary, so as to allow no carbonic oxide and as little uncombined oxygen as possible to escape by the chimney. Methods of using anthracite successfully in marine boilers have been introduced by Captain Hamilton Geary ("Journ. Roy. United Service Inst.," vol. xxi. pp. 956–968) and by Messrs. R. W. Perkins, of Swansea, and J. F. Flannery (see "Proc. Inst. N.A.," vol. 1880).

GAS-FIRED BOILERS.

General Considerations.—The use of gaseous fuel for firing steam boilers offers a ready and efficient means of overcoming various imperfections which appear in other methods of firing, and of preventing some of the difficulties which attend these methods.

The variations in the composition and quality of different coals, and even in different parts of the same seam of coal, the imperfections of hand stoking, the nature of the combustion of solid fuel, and the necessity of using a large excess of air which it involves, all tend to make hand firing with solid fuel a very uneconomical process. The use of mechanical stokers ensures regularity in the charging of the fuel, and in its distribution on the grates, but only meets in a modified degree the other difficulties, whilst it, of course, does not alter the nature of the combustion taking place, or affect the varying composition of the fuel in use. It cannot be too clearly understood that, "in order to have complete combustion, it is necessary to have an intimate mixture of, and contact between, the particles of the combustible and those of the oxygen of the air, and also to maintain, during the whole period of combustion, a temperature sufficiently high to allow of chemical action taking place freely. The employment of solid fuel, although in small pieces, prevents the realization of the one, because it is only the surface of the pieces which can be in contact with the air; and the employment of methods of combustion which necessitate the use of excess of air interferes with the other by the inevitable lowering of the temperature." "Again, with imperfect combustion, such as is common to all boiler furnaces using solid fuel, boilers are exposed to the evil of the formation of a deposit of soot (mixed more or less with dust from the ash) on their heating surface (and on that of feed-heaters, where these are used), which considerably diminishes their evaporative efficiency. The use of solid fuel, moreover, causes additional wear to the boilers by the alternate heating and cooling which result from the operation of charging or stoking, and even from the combustion itself where solid fuel must first be volatilized and then burned in the same chamber." *

The use of gaseous fuel is in direct contrast with these features. By no other means can we obtain that intimate mixture and contact between the particles of the combustible and the supporter of combustion which are essential to complete combustion. The variations in composition of coal are overcome by the process of producing gas, the volume of gas in relation to

* Gas Firing for Steam Boilers, by F. J. Rowan: "Trans. Mining Inst. Scot.," vol. v. p. 218.

the weight of solid fuel being so large that the composition of the gas remains to all intents practically constant, although that of the coal may vary. The formation of smoke and of sooty deposit is prevented, and the alternations of high and low temperature, which are destructive to the boilers, are replaced by an even temperature which the steady stream of flame supplies. The temperature of combustion is not unduly lowered by the admission of excess of air for combustion, and consequently less heat is uselessly carried off by waste gases. It does not appear that the many advantages of this system of firing boilers have been fully realized in any practice with it hitherto carried out, although very good and economical results have been obtained in the case of several examples.

On the other hand, coal fires, as applied to boiler firing, possess one advantage which renders them peculiarly suited to this work, especially where the steaming powers of boilers are forced, and that advantage consists in the large store of radiant heat which they yield when the coal is fully coked and the solid mass on the fire-bars is incandescent throughout. This quality of a coal fire has not been fully imitated in applying gas firing to boilers, but in instances of forced combustion, which are only partial applications of gas firing, its advantages are realized. Its importance has been demonstrated by an experiment shown by Mr. W. Anderson, and before him by Prof. Tyndall, where the radiation from a gas-flame is shown to be greatly increased by the presence of a solid body, which becomes incandescent or glowing in the midst of the flame. Connected with this are the questions of the calorific intensity of the fire, and of the temperature to which the heating surfaces of the boiler are exposed. These questions are not identical, for determinations of calorific intensity do not include any statement of the amount of radiant heat produced by the combustion of a fuel, or of the evaporative effect of this radiant heat. The calorific intensity of an ordinary coal fire, where twice the theoretical quantity of air required for combustion is admitted, is stated by Mr. D. K. Clark* to be about 2614° F., whilst the calorific intensity of ordinary producer gas is variously put at 1800° to 2000° by different authorities. Invariably, however, more air than 24 lbs. per lb. of coal is admitted to coal fires, and the heating effect of these fires is still further reduced by the cooling effects produced by opening the furnace-doors for stoking and cleaning the grates; but yet it appears that, given a restricted boiler heating surface, but a good chimney draught, more steam may be produced by a forced coal fire under such circumstances (though at the cost of a greatly increased expenditure of fuel) than by gas firing as ordinarily applied—viz., with cold air for combustion. This shows that the full heating effect of a coal fire is not represented by these temperatures, which denote the calorific intensity of the fuel.† On the principle that a steam boiler may be justly regarded as a heat engine, it is evident that the higher the initial temperature, T, is, the better, it being understood that this is the temperature actually operating on the boiler surfaces, provided that in maintaining this temperature we do not allow the waste gases to escape too rapidly or to be too hot when escaping, and thus unduly raise the final temperature, t.

In several instances in which gas-firing has been tested against hand-fed coal fires, under similar conditions as to amount of boiler heating surface and of chimney draught, the results have shown a higher evaporative efficiency in the gas-fired boiler—that is, a larger quantity of water evaporated from the same surfaces in a given time. A greater weight of water has also been in some cases evaporated with gas per lb. of coal used, although,

* "A Manual of Rules, Tables, and Data, &c.," third edition, 1884, p. 408.

† See On the Estimation of the Calorific Value of Solid and Liquid Fuel, by F. J. Rowan: "Jour. Soc. Chem. Indus.," vol. vii. p. 195.

where cold air has been used for combustion, the difference between the two systems of firing has not been very great in this respect. Where the air for combustion has been heated by waste heat from the exit gases, a much higher temperature of combustion and increased economy of evaporation have been obtained. In those cases in which gas firing with cold air has shown economical results, it will be found that the steaming power of the boiler has not been forced, either from insufficiency of chimney draught or from its not being necessary to obtain more steam than was being supplied. The question, however, arises, how it happens that, if the temperature of a solid coal fire is higher than that of the flame obtained from producer gas and cold air, the gas flame should be able to evaporate more water from the same surfaces in the same time. This apparently anomalous result will be found to be due to the existence in these cases of a proper relation or ratio between the extent of heating surface, the rate of travel of the flame and hot gases over the surface (or what is the same thing, the duration of contact between them and the surface), and the initial temperature or the temperature of the fire. The proof that this proper ratio exists will be found in the final temperature or the temperature of the escaping waste gases, which will show the amount of cooling which has taken place. It is evident that with an initial temperature of 2000° F. and a final temperature of 400° F., we should have a better thermal result than where with 3500° F. initial, we have 1200° F. final, the difference being as 0.8 is to 0.65.

Mr. Anderson has, moreover, directed attention to the fact that the conductivity of substances varies inversely as the temperature and probably as the absolute temperature, and hence the rate of transfer of heat to the water of a boiler will be slower in proportion at the furnace end than at the chimney end, but to what extent it is impossible to say, because the mean temperature of the boiler plates is unknown. He thinks that it is certain, however, that it is below even the melting-point of lead, or 630° F., because lead safety-plugs are frequently used even in locomotives, and they do not melt out unless there be a want of water. He says, "if we assume the mean temperature of the plates at the furnace-end to be 500°, and that of the chimney-end to be 350°, then the rate of transmission at the cooler end will be about 18 per cent. greater than at the hotter. Were it not for the imperfect absorption of radiant heat and reduced conductivity caused by high temperature, ebullition over and about the furnace would be so violent that uncontrollable priming would surely take place." This also serves to explain how a better result may be obtained with the moderate heat of a gas flame with cold air than with a hotter fire; and it further shows that in order to secure economy we must consider other elements besides the mere heat of the fire. It follows directly from these facts that higher temperatures of combustion demand greatly increased surfaces for transmission of heat to the water, or a longer period of contact of the flame and hot gases therewith, in order to reduce the temperature of the exit gases, which is necessary in order to obtain the largest useful effect from the thermic cycle of operations.

Regarding the amount of evaporation which can economically be obtained from the heating surface of boilers, Mr. W. Anderson remarks that in practice 12 square feet of flue heating surface, measuring only the half over the gases, or 10 square feet of small tube surface, measured in the same way, will transmit the heat necessary to evaporate 1 cubic foot of water (= 62 lbs.) per hour from and at 212°, which he reckons as one boiler horse-power; and that where the escaping gases have a temperature of 400° F., a mean velocity of 10.8 feet per second over the surface is admissible for them, which corresponds with 10 square inches of flue section per boiler horse-power, for a consumption of 1 lb. of coal to 10 lbs. of water converted into steam.

Mr. Thomas Box, in his "Treatise on Heat" (London: Spon, 2nd ed. 1876, pp. 85, 86), takes $\frac{2}{3}$rds of a cubic foot, or say 40 lbs., of water evaporated from 60° into steam of any pressure as equivalent to one *indicated* horse-power, and gives a formula and table showing that in boilers of fifty horse-power and upwards, about 10.6 square feet of effective heating surface are required for this work. This is equivalent to an evaporation of 4 lbs. of water from each square foot of heating surface, and also, if 8 lbs. of water are evaporated per lb. of coal, to a consumption of $\frac{1}{2}$ lb. of coal per square foot of effective heating surface.

Mr. D. Dixon, engineer to Messrs. Gadsden & Co., of New York, who had considerable experience in this application of gas firing, arrived at similar conclusions, and his observations have been, by the courtesy of Mr. H. A. Gadsden, made available for this work. Mr. Dixon remarks that the conclusions to be drawn from their experience are:—

"1st. That more water can be evaporated per square foot of heating surface with hand firing than by gas, unless the air is heated, so that as high a temperature is obtained with gas as can be derived from a coal fire; the amount of evaporation depending on the temperature and not so much on the volume of the heating gases." In this conclusion Mr. Dixon, however, does not take into account the relation of extent of surface to the temperature, initial and final, of the gases, and it is, therefore, not universally true.

"2nd. That if an evaporation of more than 7 lbs. of water per square foot of effective heating surface is obtained by gas firing, it is at an enormous expense of fuel in proportion to the increase. All the data at hand lead to the conclusion that 4 lbs. per square foot is the most economical quantity at which to work a boiler." Mr. Dixon adds, "This holds good as well in the case of hand firing."

"3rd. Brick burners give a better result than iron ones. It is most important that combustion should be complete before the gases touch the boiler. An arch built over the burners underneath the boiler, extending back 3 or 4 feet, for the gases to burn against, is very effective, a few holes can be left in it to allow a little heat to pass through. The arch, when heated, acts as a sort of regulator."

"A combustion chamber built out in front of the boiler is effective, especially with a tubular boiler—or a deep combustion chamber, with the point of mixture of gas and air not less than 6 feet from the under-surface of the boiler." These conclusions were arrived at in the year 1883 as the result of several trials of gas firing which were carried out in America, and will be described subsequently in this section.

Practical Examples.—The firing of the steam boilers in ironworks was one of the first uses to which the gases from blast furnaces were put, as soon as their recovery was commenced. An ordinary method of carrying out this application of gas fuel to boilers is illustrated in Figs. 388-390.

FIG. 388

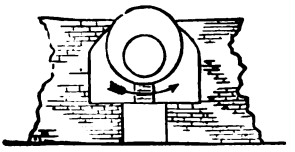
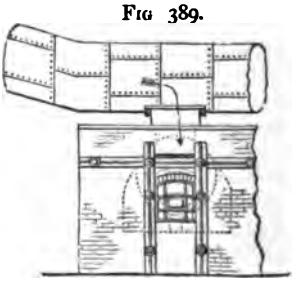
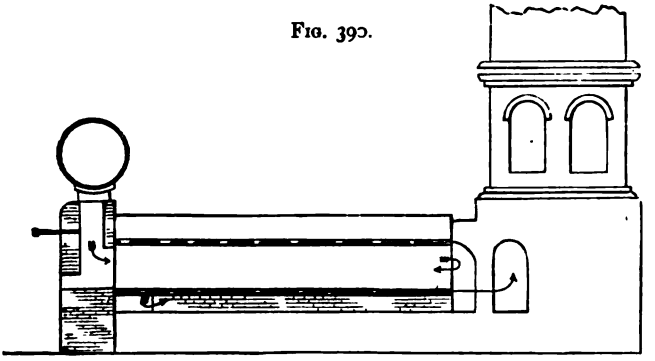


FIG 389.



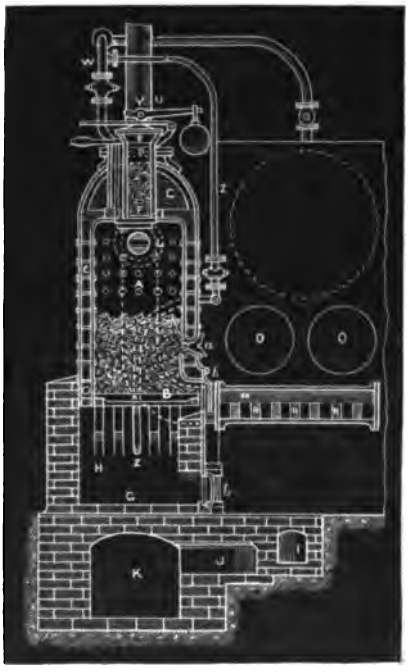
The gas is usually conveyed to the front of the boilers by over-head mains, with vertical branches leading downward, as is shown in Figs. 389 and 390. The air for combustion is generally admitted through gratings or other openings in the furnace door, through which it is drawn by the draught of a

Fig. 390.



chimney, but it is sometimes supplied from a fan or blowing engine, by means of a blast-pipe leading into the furnace or ash-pit. In order that the gas should be always ignited, some solid fuel is usually kept burning near the gas and air inlets. The experience gained in such ironworks with this system of firing boilers showed its advantages in some respects. Repairs to the boilers were lessened, and the life of the boilers was prolonged, whilst their steaming power was increased. The economy of fuel, as compared with hand firing with solid fuel, could not be investigated, for the simple reason that the quantity of gases used could not be measured. To the ironmaster, however, the use of the waste gases in this way was wholly an economy—a waste product completely taking the place of so much coal or dross.

Fig. 391.



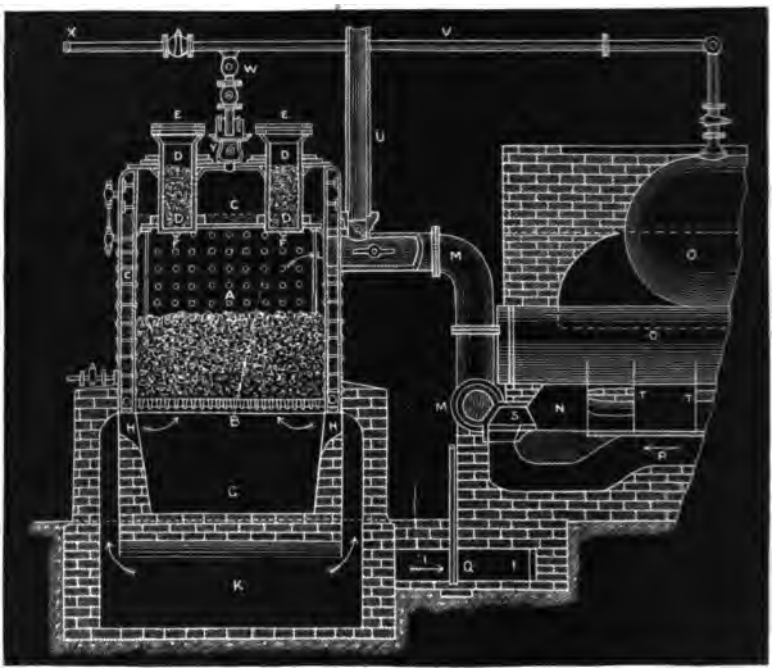
Some of the earliest comparative trials of gas firing applied to boilers, of which we have records, were carried out in France. Many attempts had been made, both in France and in Britain,* to introduce forms of apparatus or arrangements of furnaces by means of which the formation of smoke would be prevented—or, as they were termed in those days, smoke-consuming apparatus. These experiments, no doubt, paved the way for the introduction of gas firing, the earliest apparatus designed for this system as applied to steam boilers having been that of M. Beaufumé. The gas-producing part of this apparatus has

* See "Notice sur les Appareils fumivores, appliqués aux Foyers des Machines-à-vapeur et notamment aux Machines locomotives employant la Houille," par M. Turck: *Mém. et Compt. Rend. de la Soc. des Ingén. civils*, No. 36, pp. 585-628 (Paris, 1866).

been already described (see *ante*, p. 253). Figs. 391 and 392 show the combustion arrangements in connection with the boiler setting.

The gas was delivered from the gasifier A by the pipe M (Fig. 392), whence it was admitted to the fire-place by numerous small streams through the passages S (Fig. 392), formed by the bricks R (Fig. 391). The air for combustion was led from a fan into the passages K, J, and I to O, in which

FIG. 392.



it was heated, and from the latter it was allowed to escape into the combustion chamber N by the small passages S. It was thus also broken up into small streams, and well mixed with the gas. Part of the air supply was admitted to the grate B of the gasifier by the passages H (Fig. 392).

The late Professor Macquorn Rankine communicated, in October 1857, to the Institution of Engineers in Scotland,* the results of experiments made with the Beaufumé apparatus, which proved its practical usefulness.

The Table on p. 541 gives the results of the experiments made at the Imperial Arsenal at Cherbourg by order of the French Government, under the supervision of MM. Guesnet, Admiralty Engineer, and Sochet, Director of Naval Construction, by whom a report was issued.

Four series of experiments were made, the first three being with the boiler of the establishment called the Northern Forge at Cherbourg. This boiler (of 12 h.p.) had 167½ square feet of heating surface, and its ordinary grate surface was 12¼ square feet.

The Beaufumé gasifier had a grate surface of 5¼ square feet, the fuel being allowed to be 27½ inches thick on the grate. The gasifier was 11½ feet high, and measured 10 feet by 6½ feet on its width and depth respectively.

* "Trans. Inst. Eng. in Scotland," vol. i. pp. 14–18.

The fan delivering the air supply was driven at one thousand revolutions per minute, and supplied the blast at a pressure of 1.97 inch of water.

The fourth series of experiments was made with one of four tubular boilers lying in the boiler-yard at Cherbourg ready for the steamer *Antelope*.

MM. Guesnet and Sochet certified that, although there were some inconveniences connected with the system, yet the apparatus worked with great regularity; no smoke was made, and a saving of 38 per cent. was realized. They estimated the saving which might be reckoned on with certainty in ordinary work at 33⅛ per cent.

Professor Rankine supplied some additional details not given in the Report—viz.: In all the experiments the water supplied to the boiler was cold; and as it is usual to reduce the results of experiments of this kind to the results which would have been obtained if the boiler had been supplied with water at a temperature of 212° F., 18 per cent. must be added to the evaporation in series 1, 2, and 3, and 16 per cent. to that of 4; this making the results in one case 9.8 lbs., and in the other 10.5 lbs. of water evaporated per lb. of coal. In other experiments, one of the best results obtained, when water of about 100° was supplied, was equivalent to an evaporation of nearly 12 lbs. of water, from 212°, per lb. of coal.

The boiler used in the first three series of experiments was evidently a bad one, because its usual rate of evaporation, when coal was burned on the ordinary grate, was only 4.85 lbs.

RESULTS OF EXPERIMENTS MADE AT CHERBOURG.

No.	Date.	Duration of Experiments.	Total Amount of Fuel consumed.	Kind of Fuel.	Water evaporated during the Experiment.	Water evaporated per Hour.	Water evaporated per lb. of Coal.	Observations.
	1856.	h. m.	lbs.		lbs.	lbs.	lbs.	
								Series No. 1.
1	May 7	8 30	970½	Large Newcastle coal	4,620	543.5	4.865	The boiler of the forge heated by the ordinary furnace.
2	„ 8	8 31	1,014½	Large Newcastle coal	4,905	561.9	4.835	The boiler of the forge heated by the ordinary furnace.
								Series No. 2.
3	„ 28	8 45	908½	Large Newcastle coal	5,640	644.4	6.210	The boiler of the forge heated by the Beaufumé apparatus.
4	„ 29	8 30	1,058½	Large Newcastle coal	7,110	836.5	6.710	The boiler of the forge heated by the Beaufumé apparatus.
5	„ 30	8 30	1,021	Large Newcastle coal	6,621	778.5	8.260	The boiler of the forge heated by the Beaufumé apparatus.
								Series No. 3.
6	June 2	8 30	847	Small coal, Cardiff (Newall's Llanelly)	6,131	875.6	7.240	The boiler of the forge heated by the Beaufumé apparatus.
7	„ 4	8 30	811½	Small coal, Cardiff (Newall's Llanelly)	6,744	791.8	8.300	The boiler of the forge heated by the Beaufumé apparatus.
8	„ 6	8 0	761	Small coal, Cardiff (Newall's Llanelly)	5.518	689.7	7.250	The boiler of the forge heated by the Beaufumé apparatus.
								Series No. 4.
9	„ 12	7 0	1,500	Newcastle coal	12,751	1,821.6	9.035	*Weather Cold.* A tubular boiler heated by the Beaufumé apparatus.
10	„ 15	5 15	849	Newcastle coal	7,353	1,400.4	8.066	*Weather Cold.* A tubular boiler heated by the Beaufumé apparatus.
11	„ 16	7 15	1,235	Newcastle coal	12,218	1,676.2	9.820	*Weather Cold.* A tubular boiler heated by the Beaufumé apparatus.
12	„ 17	7 0	1,235	Newcastle coal	11,618	1,659.7	9.407	*Weather Cold.* A tubular boiler heated by the Beaufumé apparatus.
13	„ 18	6 0	1,058½	Newcastle coal	9,788	1,631.3	9.245	*Weather Cold.* A tubular boiler heated by the Beaufumé apparatus.
14	„ 23	5 0	1,058½	Newcastle coal	9,420	1,884.0	8.897	*Weather Temperate.* 36 out of 106 tubes closed.
15	„ 25	9 0	2,029	Newcastle coal	17,719	1,969.5	9.038	*Weather Temperate.* 36 out of 106 tubes closed.
16	„ 26	2 30	4.762	Newcastle coal	6,921	1,885.7	9.898	*Weather Temperate.* 42 out of 106 tubes closed.
17	„ 29	3 45	653	Newcastle coal	6,923	1,864.0	10.600	*Weather Temperate.* 42 out of 106 tubes closed.

The Siemens gas producer, which was introduced about the same time as Beaufumé's, was also applied to boiler firing, but we have no published

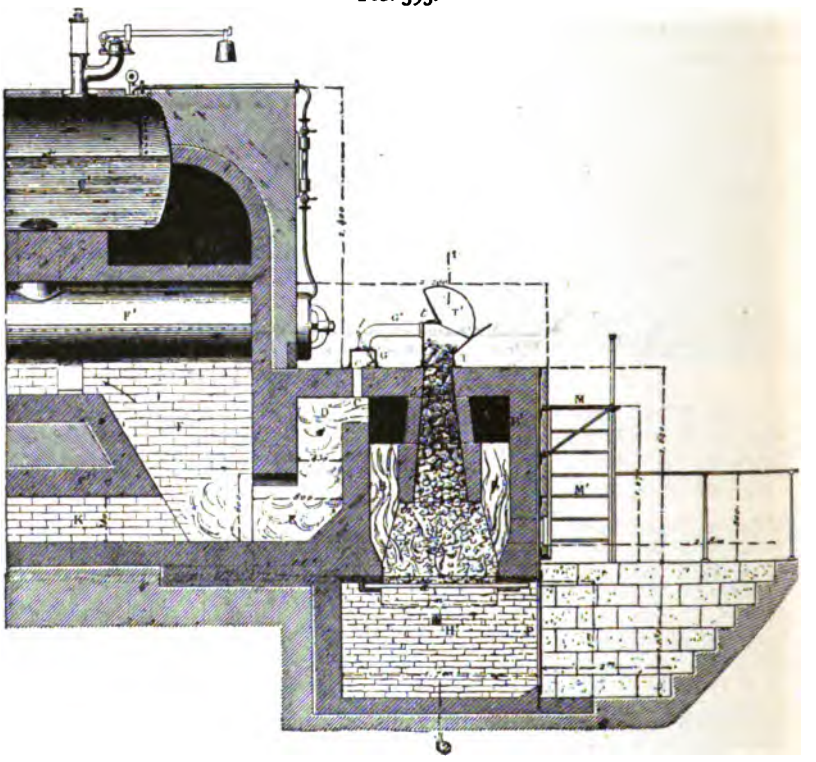
record of results of this application of it. It has not proved itself so well suited for this class of furnaces as for others.

At a very early period, the late Mr. W. Gorman worked in this direction, and in his first paper "On the Combustion of Coal,"* described experiments which showed the advantage in economy of fuel to be obtained from the use even of a modified form of gas firing. The apparatus he employed was an ordinary steam-boiler furnace, with a closed ash-pit, having blast delivered under the furnace bars and through openings in the interior surface of the double casing of the furnace door.

With ordinary air supply and chimney draught the same furnace and boiler using 28 lbs. coal, evaporated 93 lbs. of water, whilst with the blast applied and firing arranged on Mr. Gorman's system, the same weight of coal evaporated 110 and 123 lbs. of water on different occasions. Mr. Gorman displayed an intimate acquaintance with the processes of combustion, and in this paper foreshadowed the further developments in the direction of gas production, which were soon introduced.

M. E. Minary, an engineer of Besançon, published in 1868† an elaborate treatise on combustion in manufacturing furnaces, in which, after explaining the general principles and chemical reactions connected with

FIG. 393.



combustion, he described the construction and the action of his "apparatus for double combustion," as he called it, which was a gas producer with mechanical air supply, both for combustion in the producer and for com-

* "Trans. Inst. Eng. in Scotland," vol. ii pp. 70–80, and plate vi.

† *Publication industrielle des Machines outils et appareils*, &c., vol. xviii. (Paris, 1868).

bustion of the gas in the furnace. The gas-producing part of his apparatus has been already referred to (see *ante*, pp. 256–259), and in Fig. 393, the arrangement of gas producer with grate bars and closed ash-pit, and forced air supply for the double combustion, as applied to a French boiler, or *chaudière à bouilleurs*, is shown.

M. Minary's general conclusions on the subject of combustion are curious and interesting. He thus enumerates them :—

1. In all furnaces, the transmission of heat is primarily due mainly to contact of the hot gases with the fuel, with the walls of the furnace, and with the heating surface of the boilers.

2. The radiation of fires is only a reflex action, following the anterior transmission of heat by the contact of the gas.

3. It could only be otherwise for combustible bodies whose products of combustion are not gaseous, such as iron and certain metals, the oxides produced having a considerable power of radiation.

Regarding the utilization of the heat of furnaces, he concludes that :—

1. The apparatus in which combustion takes place should be perfectly distinct from the one in which the heat is utilized.

2. This apparatus should be preserved from cooling by a thickness of walls sufficient to minimize the loss of heat outwards.

3. The maintenance of a high temperature in the combustion chamber is a guarantee of perfect combustion of the gas, and it is consequently necessary to avoid reducing it for the deceptive advantage that radiation from the gas might produce.

4. The gases escaping under these conditions from the combustion chamber at a temperature so much higher than it, suffer no loss of radiation, as they take with them all the heat which has been produced, and as they are in contact with the surfaces of the generators we can recover thus nearly all the heat which the fuel can give.

M. A. Fichet* made many experiments and trials in the course of his investigation of this subject, and communicated the practical results, when he had attained to an assured success, to the French Institution of Civil Engineers.

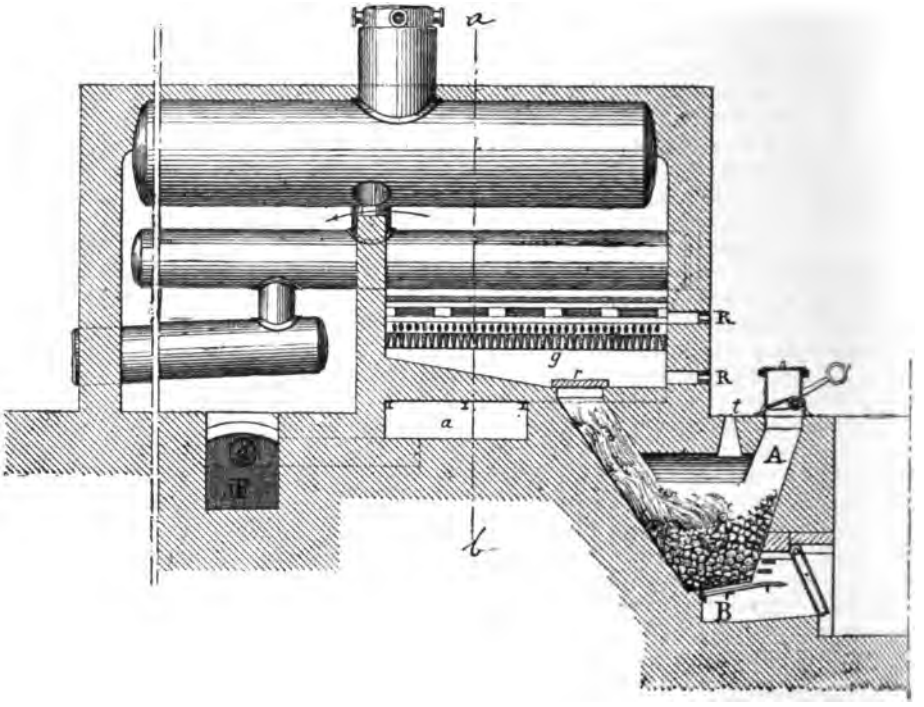
M. Fichet at first endeavoured to apply to boiler firing, with merely some modifications in details, the arrangements of gas producers and combustion chambers which he had already introduced with good results in gas-works. He found, however, that the rapid cooling of the flame and hot gases by contact with the boiler surfaces, produced phenomena which necessitated a complete change in his combustion apparatus. When using non-bituminous fuel, and admitting, for combustion of the gas, a very slight excess of air above the theoretical quantity, the flame was extinguished on contact with the boiler surfaces; but analysis of the waste gases showed the presence of both free oxygen and carbonic oxide, proving that the gas had not been completely burned. With caking coals, smoke was produced, in addition to these unsatisfactory results; but in the arrangements for firing gas retorts, these difficulties had not been encountered. Trials were therefore made of successive forms and arrangements of combustion apparatus, and the nature of the products of combustion was always observed by analysis, so that the completeness of combustion in each case was estimated. The calorific value of the gas from the generator was also measured by the calorimeter and compared with the actual result of combustion. By these means, M. Fichet arrived at various general conclusions on the subject of the combustion of fuel, which are given in his interesting memoir, and at a

* "Études sur la Combustion et sur la Construction rationelle des Foyers industrielles," par A. Fichet: *Mém. et Compt.-rend. des Travaux de la Soc. des Ingén. civils*, 1874, pp. 670–711 (Paris).

form of apparatus for boiler firing, which worked successfully, giving, as he says, complete combustion without excess of air being mixed with the products of combustion. The principles on which this apparatus rests are given as follows :—They consist in intimately mixing at a high temperature the combustible gases and air, both being divided up into thin streams, this mixing taking place in a chamber built of refractory material in which combustion (or rather inflammation) must be allowed to be complete; and, in allowing this completed mixture of gas and air to come in contact with the boiler surfaces only when its inflammation was complete, and nothing remained but to utilize the heat which was thus being produced.

Three types of this arrangement were successfully introduced—viz., as applied to a French boiler with feed-heaters (*chaudière à bouilleurs et réchauffeurs*), to a cylindrical boiler with internal furnace, and to a vertical

FIG. 394.



boiler with "Field" tubes. Figs. 394 and 395 show the first of these types Fig. 394 being a horizontal section on the line *cd* of Fig. 395, and Fig. 395 being a vertical section of the line *ab* of Fig. 394.

The first trials with this type of boiler were made at the works of M. E. Muller at Ivry.

The cylindrical portion of the boilers used was 3 feet 7 inches (1 m. 10) in diameter, with heaters or accessory chambers 24 inches (60 centimetres) diameter—the lengths are not given—and having a heating surface of 560 square feet (52 square metres), not reckoning the surface of the feed-water heaters. A producer, in the form of a modified Siemens sloping grate, of which A was the fuel chamber and B the ashpit, was placed in front of the boiler, below the floor level. The fuel was charged every hour in quantities of about 2 cwts., by means of the charging box and cover shown. Air was admitted

to the grate through perforations in the double swing-door shown at the entrance to the ash-pit. The gases produced from the fuel ascended by an inclined passage into the chamber *g* (Fig. 394) below the boiler, their rate of admission to this chamber being regulated by a damper *r*. The roof of the chamber *g* was constructed of flat pieces of fire-brick, arranged to form a grating, which provided a number of narrow openings for the escape of the gas into the combustion chamber *c* above, see Fig. 395. The air for combustion was supplied by the pipe *a* (Fig. 394) laid in the chimney flue F, in which it was heated by the hot waste gases. This pipe led into the chamber *a*, below the gas chamber *g*, from which the air ascended by passages on each side of *g*, see Fig. 395, meeting the gas in *c*, where combustion commenced. The heat imparted to the air in the pipe *a* and subsequently in the chamber *a* and passages on either side of the gas chamber, caused it to issue from the orifices into *c* with considerable velocity. It was divided into thin streams and met the streams of gas issuing in a different direction, thus

Fig. 395.

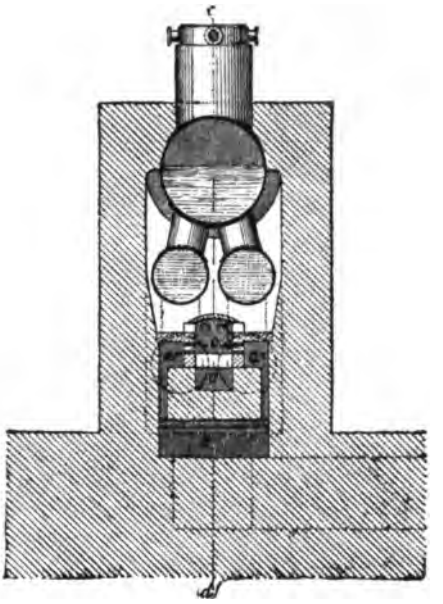
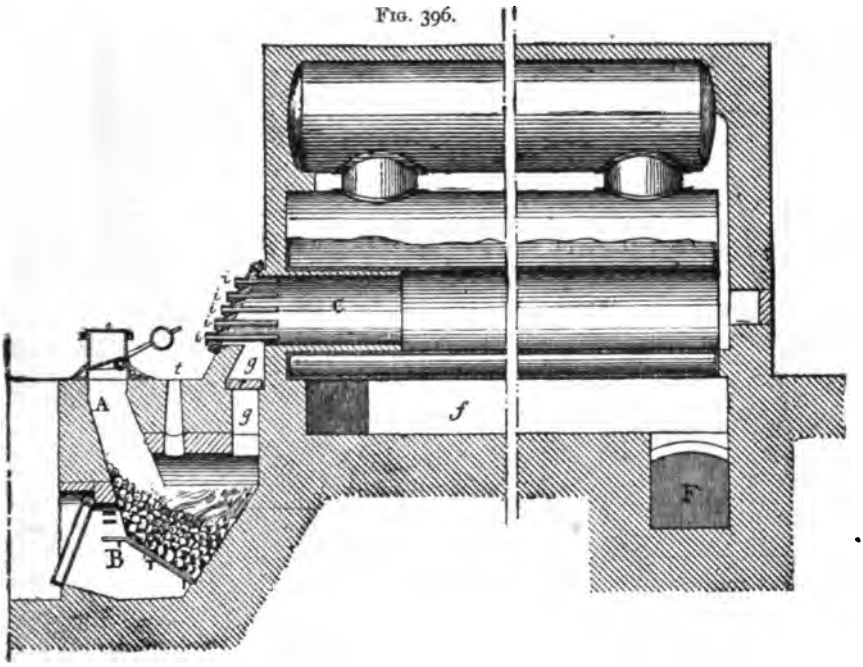


Fig. 396.



causing a thorough mixture. Although this arrangement worked well and gave good results, yet analysis of the waste gases always showed the presence of free oxygen, which was due to the admission of a slight excess of air. This excess was at last traced to leakage of air through the pores of the bricks composing the building of the boiler setting and the combustion chamber, when it did not gain admission by cracked seams formed by contraction during drying. The chimney draught sufficed to produce this filtration of air through the furnace walls, even when the air supply was delivered from a blower.

A boiler of the same dimensions, but fired by an ordinary grate, placed alongside the gas-fired boiler and supplied with the same coal and water, gave the means of instituting a comparison between the two methods of working. The boiler with ordinary grate evaporated almost constantly about 6 lbs. of water per lb. coal, the coal being the ordinary bituminous kind of the North of France and of Belgium. This rate of evaporation, M. Fichet remarks, is in accord with that obtained from the experiments carried out at Wesserling and Winterthur, and published in the *Bulletin de la Société industrielle de Mulhouse* in 1873.

The gas-fired boiler showed an evaporation of from 8.6 to 9.2 lbs. of water per lb. of coal. This, M. Fichet remarks, is equal to an increase of useful effect amounting to 48 per cent., or, otherwise, to an economy of 32 per cent. for an equal production of steam.

The feed heaters of the Ivry boiler had not a sufficient amount of heating surface to cool the waste gases below 225° C. (437° F.).

FIG. 397.

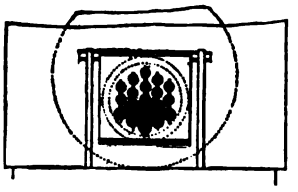


FIG. 398.

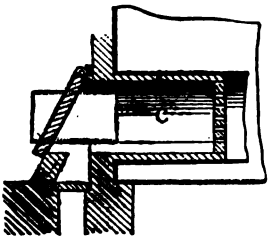


FIG. 399.

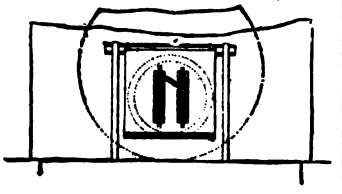
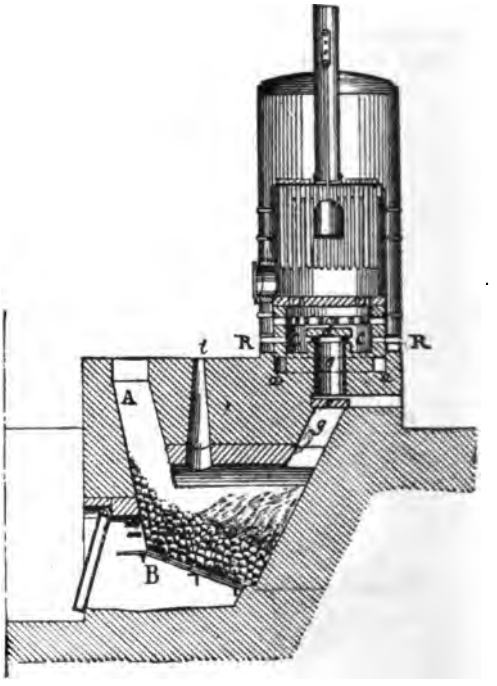


FIG. 400.



Figs. 396–399 show the arrangement for boilers with internal furnace, C being the combustion chamber, and *iiii* numerous openings in an

inclined door lined with fire-brick, which closes the outer end of the chamber C. The openings *i i* are formed by wrought-iron tubes, which conduct the air into C; in this case the chimney draught was relied on to carry the supply of air into the combustion chamber.

Figs. 398 and 399 show other arrangements of this door and its apertures. *f* and F, Fig. 396, are the flues for the waste gases leading to the chimney. The combustion chamber C is lined with fire-brick for some part of its length.

The arrangement for one class of vertical boilers is shown in Fig. 400. The gas ascends by the passage *g* and the damper *r*, and meeting the fire-brick cover *d*, it escapes by horizontal openings into the combustion space *c*, into which also air is delivered from a series of orifices connected with an annular passage *a*.

No results are given of the working of boilers of the two latter types, but M. Fichet gives tables showing the details of continuous working for a week with the French boiler. These tables are reproduced in the following pages.

TABLES OF RESULTS OF GAS FIRING APPLIED TO STEAM BOILERS.

Description of coal used	Grand Hornu
Moisture in coal (in the rough)	2.21 %
Analysis of coal (dry) { gas, 27.72 / coke, 72.78 }	100.00 %
Ash	9.36 %
Heating surface of boiler	52 sq. met. = 559.74 sq. ft.
Average pressure of steam	5 atmos. = 75 lbs. per sq. in.
Weight of coal burned in 11 hours	820 kil. = 1,808 lbs.
„ water evaporated in 11 hours	6,900 kil. = 15,224 lbs.
„ „ „ per lb. fuel	8.40 lbs.
„ „ at 0° C. (= 32° F.)	8 80 lbs.
„ „ evaporated per sq. met. of surface	12 0 kil.
„ ashes (dry) in 11 hours	72 kil. = 158.7 lbs.

Hour of Observation.	Temperature of Feed Water in Tank.	Analyses of Gases. Place where Sampled.	CO_2.	O.	CO.	N, &c.	Total.	Temperatures Observed. Degrees Centigrade. Between Boiler and Heaters.	At the End of Boiler.	In Front of Feed Water Heater.	At Back of Feed Water Heater.
	Deg. Cent.										
6 a.m.	24	. . . .	—	—	—	—	—	625			
7 a.m.	(75.2 F.)	Gasogene . .	—	—	—	100	100				
		Combust. chamber	16	—	—	84	100				
		End of boiler .	17 5	—	—	82 5	100				
8 a.m.	—	Gasogene . .	1	—	—	99	100	—	336	332	262
		Combust. chamber	17	—	—	83	100				
		End of boiler .	16.5	—	—	83.5	100				
10 a.m.	—	Gasogene . .	—	—	—	100	100	626			
		Combust. chamber	16	—	—	84	100				
		End of boiler .	16.5	—	—	83.5	100	—	326	321	
12 noon	24	. . . .									
2 p.m.	—	Gasogene . .	1	—	—	99	100	490			
		Combust. chamber	18.5	—	—	81 5	100				
		End of boiler .	16.5	—	—	83.5	100	—	398	358	
4 p.m.	—	Gasogene . .	—	—	—	100	100	—	—	—	263
		Combust. chamber	16	—	—	84	100	708			
		End of boiler .	15	—	—	85	100				
6 p.m.	29 (84.2 F.)										

Description of coal used	Grand Hornu
Moisture in coal (in the rough)	2.21 %
Analysis of coal (dry) { gas, 27.72 / coke, 72.28 }	100.00 %
Ash	9.36 %
Heating surface of boiler	52 sq. met. = 559.74 sq. ft.
Average pressure of steam	4.5 atmos. = 66 lbs. per sq. in.
Weight of coal burned in 11 hours	818 kil. = 1,803 lbs.
" water evaporated in 11 hours	6,845 kil. = 15,086 lbs.
" " per lb. fuel	8.37 lbs.
" " at 32° F.	8.83 lbs.
" " evaporated per sq. met. of surface	12.0 kil.
" ashes (dry) in 11 hours	76.5 kil. = 168.6 lbs.

Hour of Observation.	Temperature of Feed Water in Tank.	Analyses of Gases. Place where Sampled.	CO_2.	O.	CO.	N, &c.	Total.	Temperatures Observed. Degrees Centigrade. Between Boiler and Heaters.	At the End of Boiler.	In Front of Feed Water Heater.	At Back of Feed Water Heater.
	Deg. Cent.										
6 a.m.	27										
7 a.m.	(80.6 F.)	Gasogene	0.5	—	—	99.5	100				
		Combust. chamber	16.5	—	—	83.5	100				
		End of boiler	17	—	—	83	100	610	375		
9 a.m.	—	Gasogene	—	—	—	100	100	—	—	401	
		Combust. chamber	17	—	—	83	100				
		End of boiler	15	—	—	85	100	626	352	342	
12 noon	—	Gasogene	0.5	—	—	99.5	100	—	—	—	300
		Combust. chamber	13	—	—	87	100				
		End of boiler	13.5	—	—	86.5	100				
1 p.m.	25		—	—	—	—	—	629	368	442	
3 p.m.	(77.0 F.)	Gasogene	0.5	—	—	99.5	100				
		Combust. chamber	14.5	—	—	85.5	100				
		End of boiler	16	—	—	84	100	682	370		
5 p.m.	—		—	—	—	—	—	—	—	329	

Description of coal used	Grand Hornu
Moisture in coal (in the rough)	2.21 %
Analysis of coal (dry) { gas, 27.72 / coke, 72.28 }	100.00 %
Ash	9.36 %
Heating surface of boiler	52 sq. met. = 559.74 sq. ft.
Average pressure of steam	5 atmos. = 75 lbs. per sq. in.
Weight of coal burned in 11 hours	911 kil. = 2,007 lbs.
" water evaporated in 11 hours	7,850 kil. = 17 301 lbs.
" " per lb. fuel	8 61 lbs.
" " at 32° F.	9.08 lbs.
" " evaporated per sq. met. of surface	13.72 kil.
" ashes (dry) in 11 hours	89 kil. = 196 lbs.

Hour of Observation.	Temperature of Feed Water in Tank.	Analyses of Gases. Place where Sampled.	CO_2.	O.	CO.	N, &c.	Total.	Temperatures Observed. Degrees Centigrade. Between Boiler and Heaters.	At the End of Boiler.	In Front of Feed Water Heater.	At Back of Feed Water Heater.
	Deg. Cent.										
6 a.m.	24										
8 a.m.	(75.2 F.)	Gasogene	0.5	—	—	99.5	100	648			
		Combust. chamber	17	—	—	83	100				
		End of boiler	16	—	—	84	100				
10 a.m.	—		—	—	—	—	—	—	365	356	
3 p.m.	—	Gasogene	—	—	21	79	100				
		Combust. chamber	9	9	1	81	100				
		End of boiler	14 5	4	1	80.5	100	577			
5 p.m.	—		—	—	—	—	—	—	410	417	
6 p.m.	31 (87 8 F.)										

Description of coal used . . . . . Nœux, Pit No. 4
Moisture of coal (in the rough) . . . . . 2.01 %
Analysis of coal (dry) { gas, 28.87 / coke, 71.13 } . . . . . 100.00 %
Ash . . . . . 6.42 %
Heating surface of boiler . . . . . 52 sq. met. = 559.74 sq. ft.
Average pressure of steam . . . . . 4.75 atmos. = 69.85 lbs.
Weight of coal burned in 11 hours . . . . . 1,031 kil. = 2,272 lbs.
" water evaporated in 11 hours . . . . . 8,810 kil. = 19,417 lbs.
" " per lb. fuel . . . . . 8.54 lbs.
" " at 32° F. . . . . 9.33 lbs.
" " evaporated per sq. met. of surface . . . . . 15.40 kil.
" ashes (dry) in 11 hours . . . . . 126 kil. = 277.7 lbs

Hour of Observation.	Temperature of Feed Water in Tank.	Analyses of Gases. Place where Sampled.	CO_2.	O.	CO.	N, &c.	Total.	Temperatures Observed. Degrees Centigrade. Between Boiler and Heaters.	At the End of Boiler.	In Front of Feed Water Heater.	At Back of Feed Water Heater.
	Deg. Cent.										
6 a.m.	28										
8 a.m.	(82.4 F.)	Gasogene . .	1	—	20	79	100				
		Combust. chamber	8.5	5.5	2.5	83.5	100				
9 a.m.	—	" "	11	9	0	80	100	613			
10 a.m.	—	End of boiler .	11	2	5	82	100	—	384		
11 a.m.	—	Combust. chamber	14	5	0.5	80.5	100	—	—	336	
3 p.m.	26	Gasogene . .	0.5	0	20	79	100				
	(78.8 F.)	Combust. chamber	13	5.5	0.5	81	100	676			
		End of boiler .	6.5	9.5	0.5	83.5	100	—	351	—	193
5 p.m.	—	Combust. chamber	15	3.5	0	81	100	—	—	349	
6 p.m.	30										
	(86.0 F.)										

Description of coal used . . . . . Nœux, Pit No. 4
Moisture in coal (in the rough) . . . . . 2.01 %
Analysis of coal (dry) { gas, 28.87 / coke, 71.13 } . . . . . 100.00 %
Ash . . . . . 6.42 %
Heating surface of boiler . . . . . 52 sq. met. = 559.74 sq. ft.
Average pressure of steam . . . . . 5 atmos. = 75 lbs. per sq. ft.
Weight of coal burned in 11 hours . . . . . 1,127 kil. = 2,483.9 lbs.
" water evaporated in 11 hours . . . . . 11,858 kil. = 26,135 lbs.
" " per lb. fuel . . . . . 10 52 lbs.
" " at 32° F. . . . . 11.39 lbs.
" " evaporated per sq. met. of surface . . . . . 20 73 kil.
" ashes (dry) in 11 hours . . . . . 101 kil. = 222.6 lbs.

Hour of Observation.	Temperature of Feed Water in Tank.	Analyses of Gases. Place where Sampled.	CO_2.	O.	CO.	N, &c.	Total.	Temperatures Observed. Degrees Centigrade. Between Boiler and Heaters.	At the End of Boiler.	In Front of Feed Water Heater.	At Back of Feed Water Heater.
	Deg. Cent.										
6 a.m.	25										
	(77.0 F.)										
8 a.m.		Gasogene . .	1	0	20	79	100				
—	—	End of boiler .	15	2	2	81	100				
9 a.m.	—	Combust. chamber	19.5	1	0.5	79	100	751			
10 a.m.	—	" "	16	0	2	82	100		396	350	244
11 a.m.	—	End of boiler .	16	2	0	82	100				
12 noon	32										
	(89.6 F.)										
3 p.m.	—	Combust. chamber	16	0.5	0.5	83	100				
—	—	Gasogene . .	5	0	16	79	100				
—	—	End of boiler .	14	4	0	82	100				
4 p.m.	—	Gasogene . .	0	0	21	79	100	686			
5 p.m.	—	. . . .	—	—	—	—	—	—	397	376	219
6 p.m.	31										
	(87.8 F.)										

Description of coal used	Nœux, Pit No. 4
Moisture in coal (in the rough)	2.01 %
Analysis of coal (dry) { gas, 28.87 / coke, 71.13 }	100.00 %
Ash	6.42 %
Heating surface of boiler	52 sq. met. = 559.74 sq. ft.
Average pressure of steam	5 atmos. = 75 lbs. per sq. in.
Weight of coal burned in 11 hours	833 kil. = 1,829.9 lbs.
,, water evaporated in 11 hours	7,815 kil. = 17,246 lbs.
,, ,, ,, per lb. fuel	9.39 lbs.
,, ,, at 32° F.	10.12 lbs.
,, ,, evaporated per sq. met. of surface	13.70 kil.
,, ashes (dry) in 11 hours	99 kil. = 218 lbs.

Hour of Observation.	Temperature of Feed Water in Tank.	Analyses of Gases. Place where Sampled.	CO_2.	O.	CO.	N, &c.	Total.	Temperatures Observed. Degrees Centigrade. Between Boiler and Heaters.	At the End of Boiler.	In Front of Feed Water Heater.	At Back of Feed Water Heater.
	Deg. Cent.										
8 a.m.	26										
9 a.m.	(78.8 F.)	Gasogene	—	—	20	80	100				
		Combust. chamber	15	1	0.5	83 5	100	610			
10 a.m.	—	End of boiler	15	4	0	81	100	—	355	305	210
1 p m.	28	Gasogene	0 5	0	20.5	79	100				
	(82.4 F.)	Combust. chamber	13	1	4	82	100				
2 p.m.	—	End of boiler	15	1	3	81	100	659			
3 p.m.	—	. . . . .	—	—	—	—	—	—	406	381	191
4 p.m.	—	Combust. chamber	13	1	4	82	100				
		Gasogene	1	—	19	80	100				
5 p.m.	—	Combust. chamber	17	—	1	82	100				
6 p.m.	30 (80.0 F.)										

M. Fichet has remarked that these tables exhibit some anomalies, especially at the commencement of the week's work, in consequence of some inaccuracies in the apparatus employed then. He did not correct these anomalies, as they did not affect the final result, which was as follows :—

Coal burned in a week during working hours	5,540 kilos.
Water evaporated during the same time	50,088 ,,
Giving mean quantity of water evaporated per kilogram of coal burned	9.04 ,,

During the night at first, in consequence of leakage of steam and gases, 377 kilos. of coal were burned uselessly; this quantity was afterwards reduced to 80 kilos., but might have been less.

Mr. D. Clark remarks,* that "M. Fichet states, as the result of numerous observations, that in the gases supplied by the gasogene there are frequently not any traces of carbonic acid, sometimes ½ per cent., rarely 1 per cent. In the gaseous products of combustion there is not a trace of free carbonic oxide, and often there is not a trace of free oxygen. For the strongly bituminous coals, however, it is necessary to admit an excess of oxygen, of from 1 to 1½ per cent., to ensure the complete absence of smoke. This proportion of free oxygen represents an excess of air amounting to from 4 to 6½ per cent."

It is said that the plans of Messrs. Muller and Fichet were experimentally tried in Upper Silesia, at Dortmund, and at Essen, but that objections were urged against them on the score of frequent repairs being

* "Fuel, its Combustion and Economy," p. 251.

necessary. Consequently the plan illustrated in Figs. 401 and 402 was introduced by Herr A. Hartmann.*

In this plan, the fuel was introduced through a filling-hole at the floor level in front of the boiler, and covered an inclined step-grate to a thickness

Fig. 401.

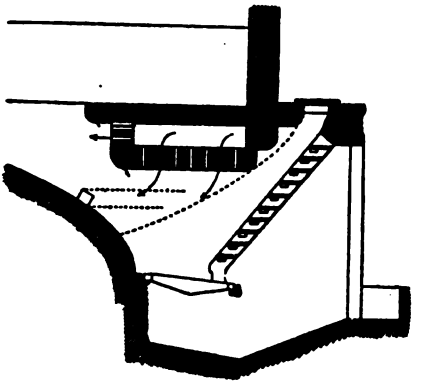
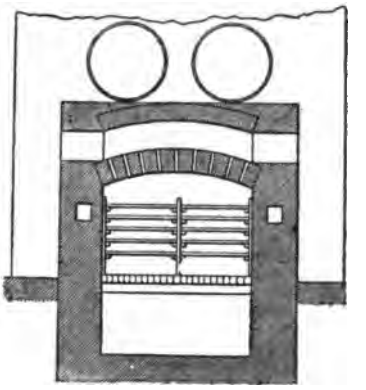


Fig. 402.



of 6 to 8 inches, reaching a thickness of about 14 inches on the bottom part of the grate, which was level. The form of the bars on the inclined slope prevented the fuel falling through to the ashpit, and enabled very small coal to be used. Two concentric arches were built over the producer, having a channel for air between them, the lower one having openings pierced through it for admitting the air to the gas chamber. The current of air kept the perforated arch cool and prevented its rapid destruction by the heat of combustion.

Herr Haupt, of Brieg,† in Silesia, devoted much study to this question, and in particular endeavoured to simplify the construction of the producer and to arrive at the best method of mixing the gas and air together.

His first experiments were "undertaken‡ to determine the best means

Fig. 404.

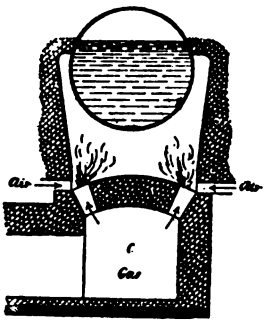
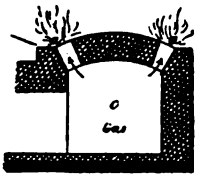


Fig. 403.



for bringing the gas and air into contact; and Figs. 403, 404, 405, 406, and 407 show the different stages by which he arrived at the most favourable results, Figs. 404 and 405 representing two different arrangements of fire-brick arches used for obtaining thorough mixture of the gas and air."

"The distance from the bottom of the boiler to the top of the fire arch

* See "Engineering," Jan. 2, 1880. † *Chemiker Zeitung* for 1880, p. 290.
‡ "Engineering," Jan. 2, 1880, p. 3.

was found to exercise a very marked influence on the results obtained, the most suitable distance having been found experimentally to be about 22 inches

Fig. 405.

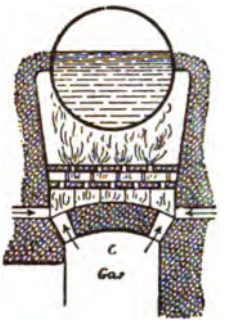
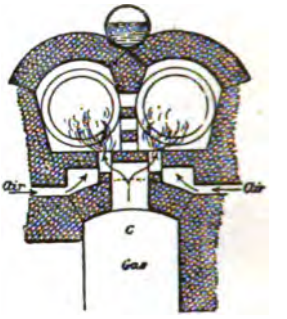


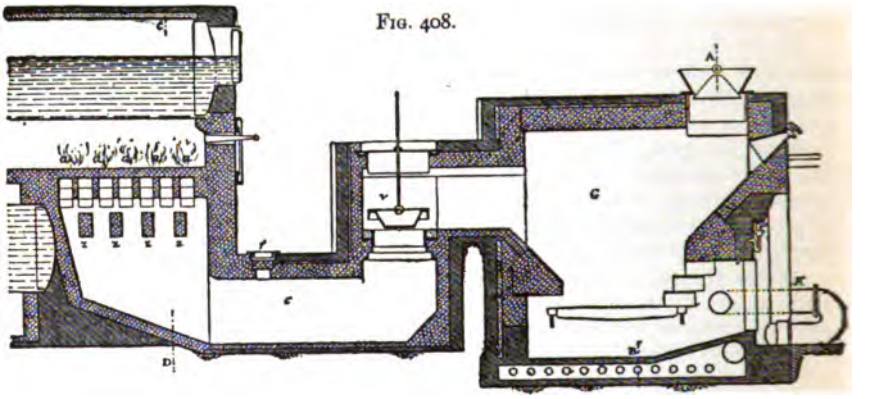
Fig. 406.

Fig. 407.



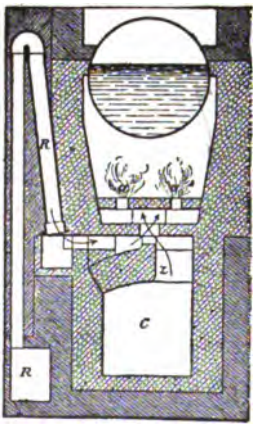
to 24 inches. The arrangement shown in Fig. 405 was worked day and night for six weeks with small coal from the Florentine pit in Upper Silesia, and

Fig. 408.



the evaporation obtained per pound of coal was equivalent to 8.4 lbs. of water at atmospheric pressure from feed water at 32° F." With caking coal, an evaporation of 9.6 lbs. of water was obtained. These results led to trials of a modification of the plans as applied to two boilers belonging to the Lower Silesian Mining Union, which were used for experimentally determining the evaporative powers of different kinds of coal.

Fig. 409.

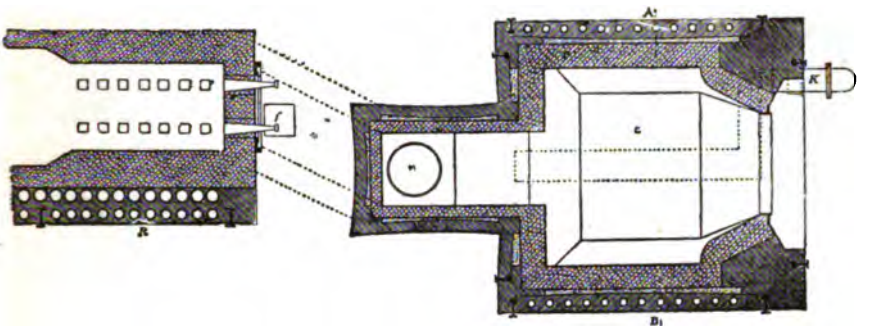


Figs. 408, 409, 410, and 411 show the modifications which were adopted in this case.

In these plans, *G* is a separate gas producer, with grate-bars and charging hopper with cup and cone, the air supply of which was forced in under the grate by a Körting blower by the pipe *K*, after having been heated by passing through tubes in the sides and bottom of the producer brickwork. This air attained a temperature of 185° to 194° F. Fig. 408 shows a longitudinal elevation in section, Figs. 409 and 411 vertical cross sections, and Fig. 410 asectional plan. *v* is a gas-valve, *C* the gas-flue, and *f* is a torch-hole

used for lighting the gas at starting. Under the boiler, the gas-flue *C* is arched over by bricks *z*, leaving alternate spaces for gas exits. The air for combustion is heated in the vertical pipes *R* (Figs. 409, 410), which it

FIG. 410.



reaches from the passage *R* (Fig. 409). It passes horizontally over *z* to meet the gas, and the mixture burns at the openings *a a a a*.

On account of want of space from the proximity of the next boiler, the one-sided combustion arrangement shown in cross section in Fig. 409 was adopted, but had soon to give way to the alteration shown in Fig. 412. "It was observed that the maximum temperature was produced about *a a* in Fig. 412, and that at *b b* it had decreased to about 1770° F. This fact accounts for the durability of the fire-brick arches, as well as for the immunity of the bottom of the boiler from injury." Several difficulties were met with in the management of the producer; but these were due partly to frequent changes in the quality of coal used—different kinds being experimented with—and partly to the producer having been worked with air blast alone. The method of lighting the gas also introduced difficulties, as, in spite of the exercise of great care, explosions occurred. This was probably the result

FIG. 411.

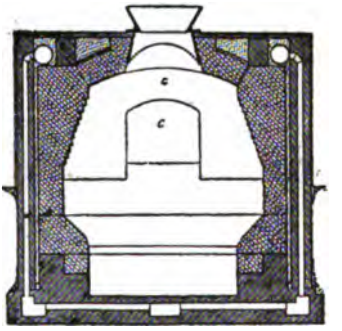


FIG. 412.

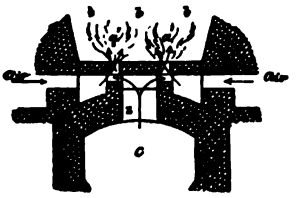
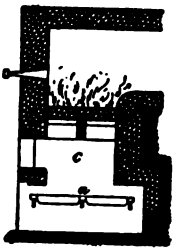


FIG. 413.

FIG. 414.



of placing the lighting-hole *f* badly. The proper position would seem to be above *a a*, where the sight-holes are placed, for here the air and gas are mixed, and the flame cannot flash back below the upper side of the arches *z*.

"In order to arrive practically at the best form and proportions for the

producer of a new and simpler kind, the experimental furnaces shown in Figs. 413 and 414 were built, the bottom of the fire-arch being kept at a distance of about 2 feet above the grate level. Several kinds of fuel were

Fig. 415.

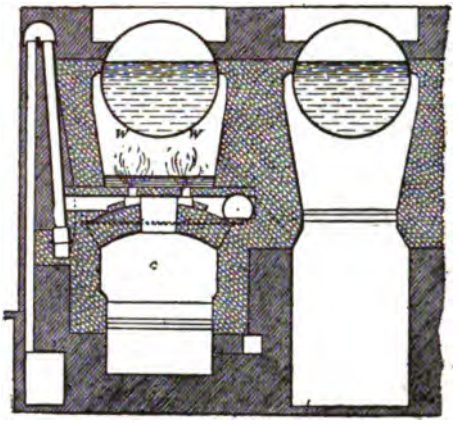
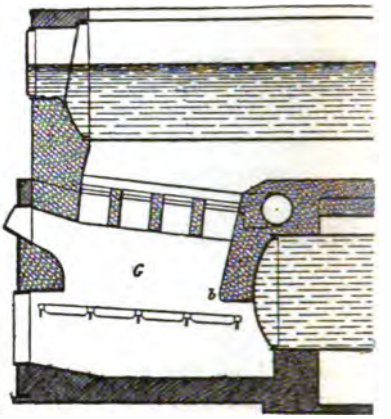


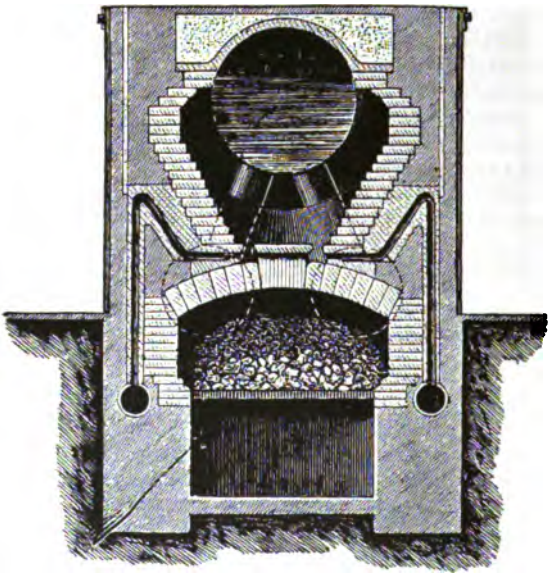
Fig. 416.



tried, some containing as much as 50 to 60 per cent. of ash, as well as the mud remaining in the coal-washing machines; but even with these very unfavourable fires it was impossible to choke the furnace."

Figs. 415 and 416 show the arrangement which was finally adopted, with which it was found possible to evaporate from 1½ to 2½ lbs. more water per lb. of coal than had been evaporated when the boiler was fired in the ordinary way, double the weight of steam being moreover produced in a given time.

Fig. 417.

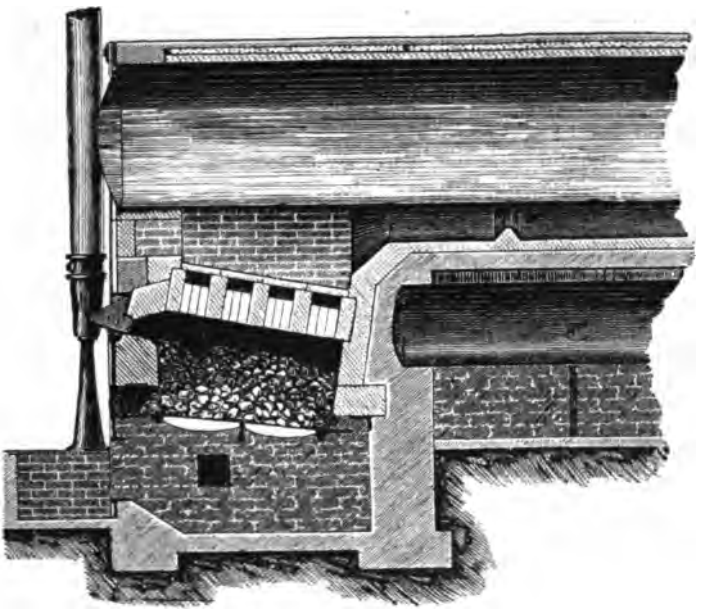


"In a trial carried on for eleven hours, the coal-fired boiler evaporated about 11,000 lbs. of water at a pressure of 90 to 105 lbs. per square inch, the feed temperature being 50° F. The total heating surface exposed was 430 square feet, which gives, say, 2.325 lbs. of water evaporated per square foot of heating surface per hour. Under similar conditions the gas-fired boiler evaporated from 23,540 lbs. to 29,000 lbs. of water, or, say, from 4.41 to 5 lbs. per square foot of heating surface per hour; and even at this high rate of evaporation the temperature in the flue leading to the chimney never exceeded 662° F. The most rapid evaporation possible with the coal-fired boiler was 19,250 lbs.; but

the temperature of the escaping gases then rose to 932° F., and the evaporation of water per lb. of coal diminished to 6 lbs. to 6½ lbs. The temperature at *W* (Fig. 415), just under the boiler surface, was found by Weinhold's pyrometer to be 2306° F., which is considered to be below what is often produced under boilers fired in the ordinary way." After five months' work, the only place showing signs of wear was the fire-brick hanging bridge *b* (Fig. 416) which protected the end of the heater, the moderate wear being considered to be due to the moderate temperature and uniformity of heating produced by the gas firing.

Figs. 417 and 418 show the most recent form of this arrangement for gas firing. By this method, the air for combustion is heated to from 280° to 295° C. by a simple arrangement of tubes. In the transverse section, Fig. 417, an inlet pipe of 10½ to 11 inches (265 to 285 mm.) diameter is shown extending along each side of the firing chamber. From these branch off small vertical tubes of 2½ to 3 inches diameter, their ends dipping down-

FIG. 418.



wards and ending in horizontal passages facing those from which the gas issues on its ascent through the roofing arch of the producer. The highest temperature observed in the combustion chamber is stated to have been 1039° C. A Körting's blower is used, as shown in Fig. 418, which gives control of the fire and (by means of the steam used in the blower) heats the air delivered from 6° to 10°. The steam, as is well known, also acts favourably as regards gas production, and with Haupt's apparatus a spray of water is sometimes also used under the grate in order to keep the bars cool.

Coal containing from 20 to 80 per cent. of ash, shale with 50 to 60 per cent. of ash, slack coal, small turf, tar, and lignite have been used as fuel. With coal from Lower Schleswig, an evaporation of 8.7 lbs. of water per lb. of coal was obtained. With grate firing, 10 to 12.06 kilos. were evaporated per square metre of surface, whilst gas firing evaporated 19.85 kilos., and with Hungarian lignite as much as 22.08 kilos. With the lignite from Edderitz, near Cöthen, the evaporation was increased 25.2 per cent. as com-

pared with ordinary grate firing, and the useful effect of the boiler 64.7 per cent.

Similar experiments in the sugar refinery at Gutschdorf gave an economy of 38 per cent. of coal, whilst other experiments are said to have given 53 to 64 per cent.

The waste gases contained 2 to 3 per cent. of free oxygen, 0.1 to 0.3 per cent. of carbonic oxide, and 12.5 to 14.7 per cent. of carbonic acid. The quantity of soot and dust in the flues was found to be nine times more with grate firing than with this system, and a smaller amount of chimney draught was sufficient. With a separate producer, the deposit of soot and dust in the boiler flues may be altogether prevented.

The following Table gives results of trials carried out at the experimental station at Brieg; No. I. being a boiler with grate fired in the ordinary way, and No. II. a boiler fitted with gas firing. Each boiler had 40 square metres of heating surface, and the draught in both cases was alike. The steam pressure, also in both cases, was 6 to 7 atmospheres.

TABLE OF COMPARATIVE RESULTS WITH HAND AND GAS FIRING.

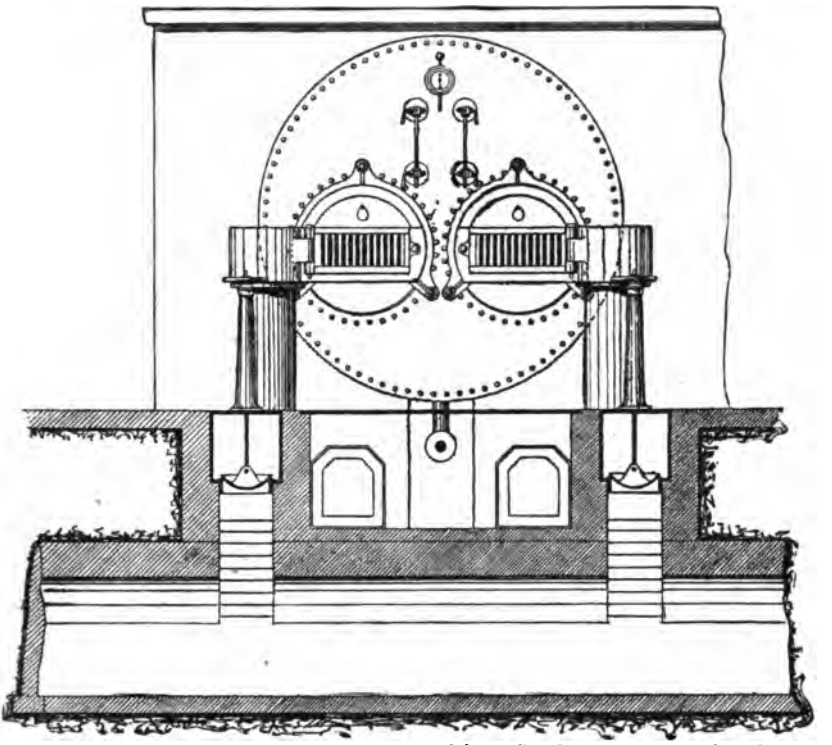
	Boilers.		Boilers.		Boilers.		Boilers.		Boilers.		Boilers.	
	I.	II.	I.	II.	I.	II.	I.	II.	I.	II.	I.	II.
Kilos. of coal burnt in 11 hours	532	834	530	864	643	872	1,568	1.785	1,543	2,030	1,550	2,020
Kilos. of water evaporated in 11 hours from 0° to 100° C..	4,438	8,224	4,629	8,354	5,305	8,735	6,284	9,716	4,016	6,619	4,174	6,567
Kilos. of water evaporated by 1 kilo. coal	8.343	9.86	8.743	9.73	8.283	10.07	4.023	5.443	2.569	3,251	2.764	5.158
Temperature in cross flue .	237°	271°	233°	249°	239°	253°	332°	254°	244°	223°	240°	225°
Do. in combustion chamber .	930°	1011°	916°	1018°	911°	1002°	890°	933°	870°	920°	860°	915°
Percentage of carbonic acid in cross flue	8.0	14.9	11.1	13.9	9.1	13.9	8.9	13.1	8.3	13.3	8.7	12.5
Kilos. of water evaporated per sq. met. of surface per hour.	10.09	18.69	10.52	18.99	12.06	19.85	14.28	22.08	9.13	15.04	8.7	14.22
Rise of effect of coal . .	—	18%	—	12%	—	20%	—	35%	—	25.2%	—	14.3%
Do. absolute effect of boiler .	—	85%	—	80%	—	64%	—	54%	—	64.7%	—	63.4%

The following Report gives the results of a very carefully conducted series of comparative trials of gas and hand firing made by Mr. J. H. Darby, engineer to the Plas Power Colliery at Wrexham. He employed two boilers of the Lancashire pattern of identical design and dimensions, one (illustrated in Figs. 419 and 420) being fired by gas from a Wilson producer with the arrangement of furnaces, gas-valves, &c., as shown in these Figs. 419 and 420, but without any elaborate arrangement of boiler setting as in the French experiments, and with the minimum of brickwork in the combustion arrangements. The other was fired by hand in the usual way. Measurements of the water and coal used, and analyses of all gases from the producer and in chimney flues,* were made, and the *modus operandi* was slightly altered in the experiments in order to ascertain the best way of working. The result he has stated to be an average increase of duty of 27 per cent. in favour of the gas-fired boiler.

The two boilers selected for the experiments were set side by side, and of the following size and dimensions:—Length, 27 feet; diameter, 7 feet; with internal flues of the Lancashire pattern, seven diagonal tubes being placed in each flue. Effective heating surface in each boiler, 443 square feet. No. 1 was heated by gas from a Wilson producer. No. 2 was hand

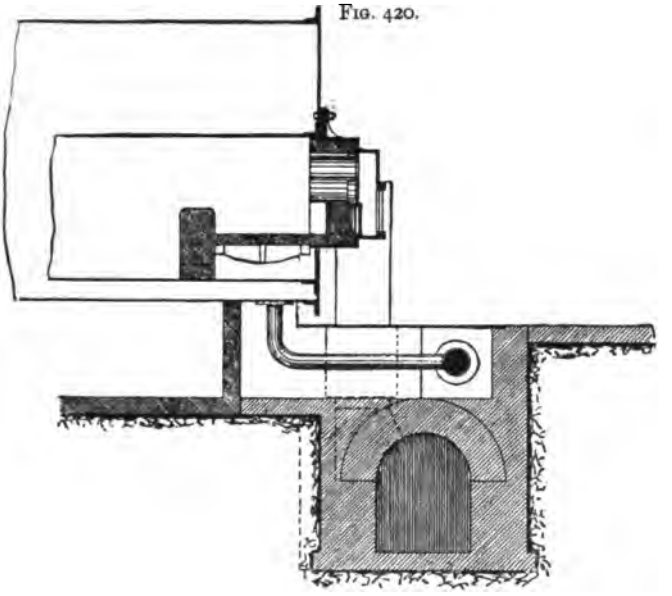
* Examinations of the waste gases from two boilers similarly fired by gas from Wilson producers at Messrs. Tangye's Steel Works, Birmingham, were made by Pattinson and Stead, who certified that the average of six analyses gave 13.20 per cent. of carbonic acid, precautions having been taken to remove sulphur dioxide before treating the gases with potash. This result shows a completeness of combustion equal to that shown by the analyses in Mr. Darby's trials.

Fig. 419.



Elevation of double-flue boiler arranged for gas firing—Gas flue in longitudinal section.

Fig. 420.



Double-flue boiler arranged for gas firing—Section through one flue and firing-door—Gas flue in cross section.

fired by the usual method. The feed water was supplied from two iron tanks by a pump:—

No. 1 tank supplying No. 1 boiler, measuring 15′ 11¼″ × 7′ 0″
No. 2 tank supplying No. 2 boiler, measuring 15′ 11¼″ × 6′ 11¼″

The gauge of the tanks was then:—No. 1, 581 lbs. water per inch depth; No. 2, 576 do.

The draught caused the burnt gases to pass first along the internal flues, then back along the bottom of the boiler, splitting at the front into a flue on each side, and along these to the main flue.

In trial No. 1, the hand-fired boiler was worked, as is usual at the colliery, with the damper open, and a draught of 16 to 20 millimetres (0.6 to 0.78 of an inch) of water, so as to burn the inferior fuel.

In trials Nos. 2 and 3, with the same boiler, the draught was regulated to 9 millimetres (3½ tenths of an inch), the fires being so worked that the red fuel was pushed forward towards the bridge, while the green fuel was being coked near the deadplate. There was, however, much trouble in burning the inferior fuel by this method of firing, the boiler taking the entire attention of one stoker.

Description of coal used:—Refuse.

TRIAL No. 1.—Nos. 1 and 2 Boilers.

Duration of trial	11 hours
Draught	16 to 20 millimetres ($\frac{6}{10}$ths to nearly $\frac{8}{10}$ths of an inch)
Pressure of steam	50 lbs. per square inch

No. 1 Boiler (Producer).

Used 8,260 lbs. of fuel
„ 47,932 lbs. of water = 4,357 lbs. per hour
1 lb. of fuel evaporated 5.8 lbs. of water
Fuel gave clinker and refuse 13.5 %
Temperature of water for feed, 40° C. (= 104° F.)
Pressure of gas in producer, 20 millimetres = nearly $\frac{8}{10}$ths of an inch
Carbonic acid in gases issuing from the end of internal flues, 8.2 %

Sample of gas from producer gave on analysis:—

Carbonic acid	7.14
Oxygen	0.00
Hydrogen	12.15
Carbonic oxide	19.83
Marsh gas	3 61
Nitrogen	57.24
	99.97 %

Temperature in annular flue of producer, 960° C. (= 1760° F.)
„ above gas-valve under boiler, 740° C. (= 1364° F.)
„ of fuel in producer, 1300° C. (= 2372° F.)

No. 2 Boiler (Hand Fired).

Used 6,160 lbs. of fuel
„ 32,616 lbs. of water = 2,965 lbs. per hour
1 lb. of fuel evaporated 5.3 lbs. of water
Fuel gave 16.6 % of clinker and refuse
Temperature of feed water, 40° C. (= 104° F.)

In the foregoing trials, the fuel burnt as gas in No. 1 boiler gives a better duty by 9.4 % than the same class of fuel burnt under No. 2 boiler

by hand firing, the duty done by each boiler per hour being in favour of the gas-fired boiler.

Gas-fired boiler, 4,357 lbs. of water evaporated per hour
Hand-fired „ 2,965 „ „ „

With the temperature of the feed water at 100° C. (= 212° F.), and the steam at atmospheric pressure, the duty per lb. of fuel would be as calculated:—

No. 1 gas-fired boiler, 6.86 lbs. of water evaporated per lb. of fuel
No. 2 hand-fired „ 6.26 „ „ „

Before making trial No. 2, various tests were taken to ascertain what conditions of draught were most favourable to a high percentage of carbonic acid in the burnt gases.

TRIAL No. 2.—Nos. 1 and 2 Boilers.

Description of fuel:—Refuse from screens.

Duration of trial	9½ hours
Draught	9 millimetres of water (3½ tenths of an inch)
Pressure of steam	50 lbs. per square inch

No. 1 Boiler (Producer).

Used 6,104 lbs. of fuel
„ 39,943 lbs. of water = 4,204 lbs. per hour
1 lb. of fuel evaporated 6.5 lbs. of water
Fuel gave 12.6 % of clinker and refuse
Temperature of feed water, 30° C. (= 86° F.)
Pressure of gas in producer, about 20 millimetres (nearly $\frac{8}{10}$ths of an inch)

Carbonic acid gas, in gases issuing from end of internal flues	13.4 %
With slightly redder flame, carbonic acid	16.2 %
Oxygen	1.4 %
Carbonic oxide	0.8 %

Temperature of gases in annular ring of producer, 750° C. (= 1382° F.)
„ „ in valve below boiler, 570° C. (= 1058° F.)
„ of waste gases in flue to chimney, 320° C. (= 608° F.)
„ of air heated by waste gases before combustion, 120° C. (= 248° F.)

In this trial, the level of the fuel in the producer was about 4 feet from the ground.

No. 2 Boiler (Hand Fired).

Used 4,704 lbs. of fuel
„ 29,880 lbs. of water = 3,145 lbs. per hour
1 lb. of fuel evaporated 6.3 lbs. of water
Fuel gave 13.6 % of clinker and refuse
Temperature of feed water, 30° C. (= 86° F.)

Carbonic acid in end of internal flues	10.0 %
Oxygen	8.9 %
With slightly redder flame—Carbonic acid in end of internal flues	14.2 %
„ „ Oxygen	4.6 %

In No. 2 trial, the fuel burnt as gas in No. 1 boiler gives a better duty by 3.2 % than the same class of fuel burnt under No. 2 boiler by hand firing. But contrasting the duty done by No. 1 boiler during No. 2 trial with the duty done by No. 2 boiler in No. 1 trial, there is a better duty given by No. 1 boiler over No. 2 boiler of 22.6 %. With the temperature

of the feed water at 100° C. (= 212° F.), and the steam at atmospheric pressure, the duty per lb. of fuel would be as calculated :—

No. 1 boiler (gas fired) 7.8 lbs. of water evaporated per lb. of fuel
No. 2 „ (hand fired) 7.5 „ „ „

The duty done by each boiler per hour is in favour of the gas-fired boiler, as under :—

Gas-fired boiler, 4,204 lbs. of water evaporated per hour
Hand-fired „ 3,145 „ „ „

TRIAL No. 3.

It was resolved to try the fuel in the producer at a higher level, in order, if possible, to reduce the temperature of the gases on leaving the producer, and also to reduce the percentage of carbonic acid in the gases.

Nos. 1 and 2 Boilers.

Duration of trial	9 hours
Draught	9 millimetres of water (= 3½ tenths of an inch)
Pressure	50 lbs.
Description of fuel	Best coal

No. 1 Boiler (Producer).

Used 3,948 lbs. of fuel
„ 33,916 lbs. of water = 3,768 lbs. per hour
Fuel gave 12.5 % of clinker and refuse
Temperature of feed water, 30° C. (= 86° F.)
Pressure of gas in producer, about 22 millimetres (= 8½ tenths of an inch)

Carbonic acid in gases issuing from end of internal flues	14.0 %
Oxygen	2.8 %

An analysis of the gases, taken when the producer seemed to be at its best, and a larger quantity of steam entering by steam jet, at a lower velocity than in the former trials, gave :—

Carbonic acid	4.11
Oxygen	0.00
Hydrogen	12.42
Carbonic oxide	26.48
Marsh gas	5.91
Nitrogen	51.06
	99.98

An analysis of the average of three samples, which may be taken as a fair average analysis of the gases, gave :—

Carbonic acid	6.26
Oxygen	0.00
Hydrogen	14.68
Carbonic oxide	23.98
Marsh gas	4.72
Nitrogen	50.36
	100.00

Temperature in annular flue of producer, 600° C. (= 1112° F.)
„ in valve below boiler, 450° C. (= 842° F.)
„ of waste gases in flue to chimney, 290° C. (= 554° F.)
„ of air heated by waste gases before combustion, about 120° C. (= 248° F.)

In No. 3 trial the level of the fuel in the producer was about 6 feet from the ground.

No. 2 Boiler (Hand Fired).

Used 3,724 lbs. of fuel
„ 29,520 lbs. of water = 3,280 lbs. per hour
1 lb. of fuel evaporated 7.9 lbs. of water
Fuel gave 11.6 % of clinker and refuse
Temperature of feed water, 30° C. (= 86° F.)

In No. 3 trial, the fuel burnt as gas in No. 1 boiler gives a better duty by 8.86 % than the same class of fuel burnt under No. 2 boiler by hand-firing. With the temperature of the feed water at 100° C. (= 212° F.), and the steam at atmospheric pressure, the duty per lb. of fuel would be as calculated :—

No. 1 boiler (gas fired) 10.33 lbs. of water evaporated per lb. of fuel
No. 2 „ (hand fired) 9.49 „ „ „

	No. 1 Trial.			No. 2 Trial.			No. 3 Trial.		
	lbs. of Water Evaporated by 1 lb. of Fuel, Feed Water at 100° C., Steam at Atmospheric Pressure.	lbs. of Water Evaporated by 1 lb. of Fuel.	Water Evaporated per Hour in lbs.	lbs. of Water Evaporated by 1 lb. of Fuel, Feed Water at 100° C., Steam at Atmospheric Pressure.	lbs. of Water Evaporated by 1 lb. of Fuel.	Water Evaporated per Hour in lbs.	lbs. of Water Evaporated by 1 lb. of Fuel, Feed Water at 100° C., Steam at Atmospheric Pressure.	lbs. of Water Evaporated by 1 lb. of Fuel.	Water Evaporated per Hour in lbs.
No. 1 Boiler (gas) .	6.36	5.8	4,357	7.8	6.5	4.204	10.33	8.6	3,768
No. 2 Boiler . .	0.26	5.3	2,965	7.5	6.3	3,145	9.49	7.9	3,280

In summing up the results of the foregoing tests, Mr. Darby remarked that "the No. 1, or gas-fired boiler, was under considerable disadvantage through all the trials, owing to only one producer being at work to supply it, the quantity and composition of the gases varying so much from one addition of fuel to another that it was almost impossible to regulate the supply of air for combustion to the adequate amount. If we had several producers working together, the duty done by the fuel would have been better. On the other hand, I do not think that the hand firing in the Nos. 2 and 3 trials could be improved, as the greatest care was taken.

"With our bituminous coal, it does not answer to run the producer as high as in trial No. 3. A large quantity of tar was formed in the flues and around the valves, and would have quickly obstructed the passage of the gas.

"As regards labour costs in each method, if all our boilers (seven in number) were fired by gas, we should require six producers of the 4 cwt. per hour size, one to be always off for cleaning; but this would generate more steam than we require. The gas-fired boiler making 32 % more steam than the hand-fired boilers in a given time, or after deducting the steam used by the steam jet (= 170 lbs. of water per hour) gives 26.9 % more duty. Therefore, I think that five producers, four working and one off for cleaning, would make all the steam we require, and would take six men to work them. Six men are at present required to fire the seven boilers as in trial No. 1, but to fire them as in trials Nos. 2 and 3 it would require eight men."

With reference to the concluding paragraph in this report it must be remarked that Mr. Darby estimated the number of men required to work five gas producers by simply multiplying the labour required for one. This,

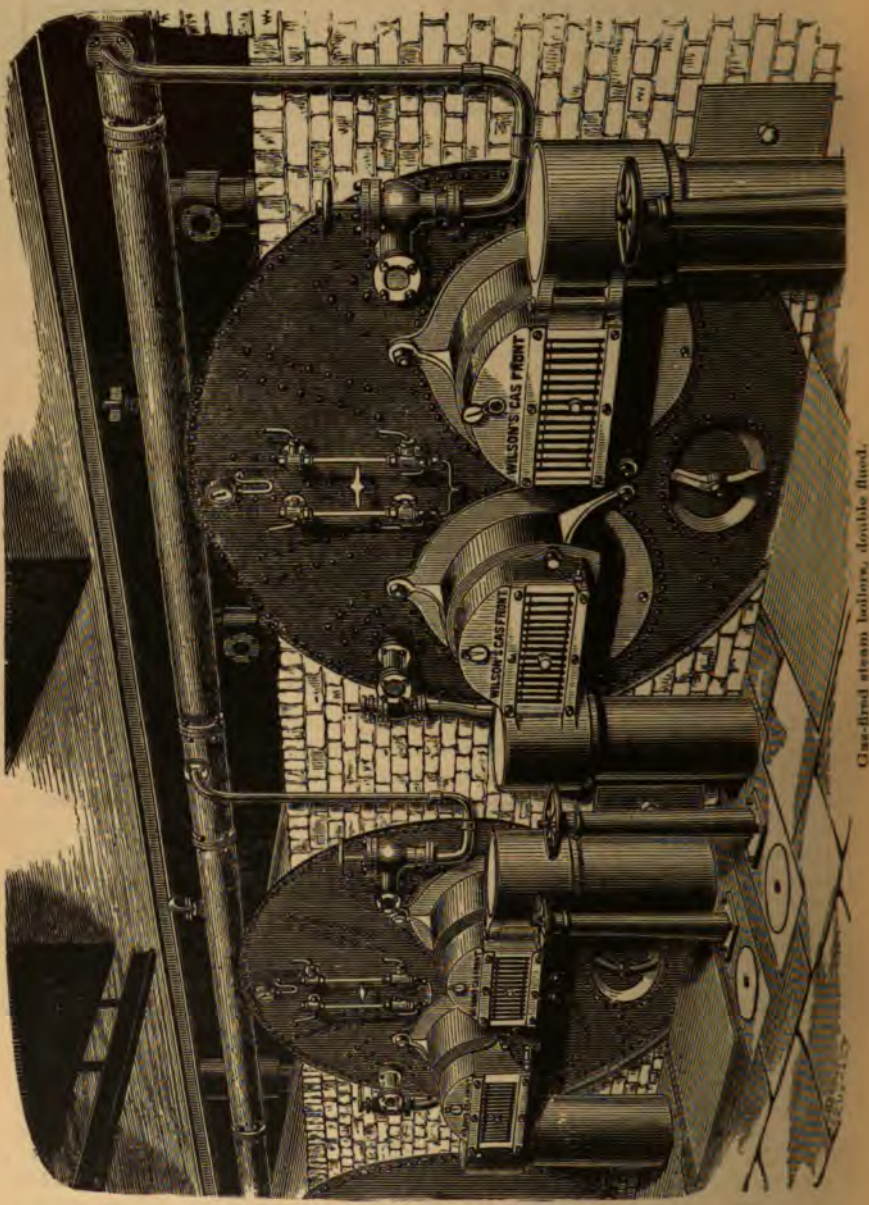


FIG. 421. Gas-fired steam boilers, double fired.

however, is an erroneous estimate, for it is found in practice that four men are enough to work seven or eight such producers.

The Table on p. 564 gives the results of careful observations of gas-firing trials carried out with boilers 30 feet long and 7 feet diameter, with

2 feet 8 inches diameter of flues, supplied with gas from Wilson producers. The illustrations Figs. 421 and 422 show the general arrangement of boiler

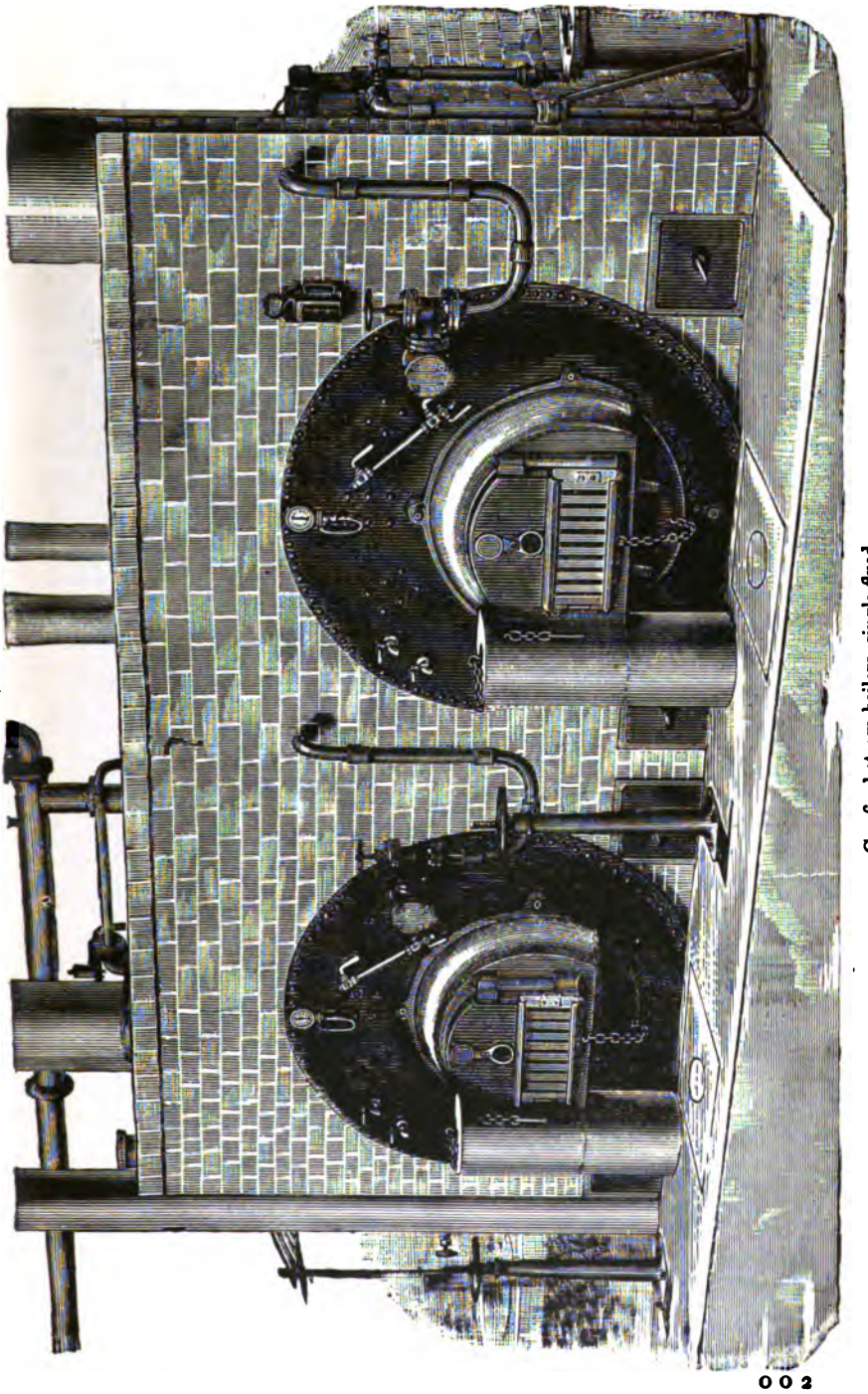


FIG. 422.

Gas-fired steam boilers, single fired.

RESULTS OF TRIALS OF GAS FIRING APPLIED TO STEAM BOILERS.

Date of Trials, 1884.	Duration of Trial in Hours.	Class of Fuel.	Height of Fuel in Producer from Bottom of Casing.	Pressure of Steam.	Amount of Draught in Boiler Flue.	Colour of Flame as seen from End of Boiler Flues.	CO_2 in Producer Gas.	Temperature at End of Boiler.	CO_2 in Escaping Gases.	Temperature of Waste Gases to Chimney.	Temperature of Feed Water.	Total Water used.	Water used per Hour.	Total Coal used.	Coal used per Hour.	Water Evaporated per lb. Coal. Feed Water 40° C. Steam 50 lbs. per Square Inch.	Calculated Evaporation, Water at 100° C., or Steam at Atmospheric Pressure.
			feet.	lbs. per sq. in.	mm. of water.		per cent.	Deg. Cent.	per cent.	Deg. Cent.	Deg. Cent.	lbs.	lbs.	lbs.	lbs.	lbs.	lbs.
August 12	11	Main coal	6′ 0″	50	6	Dull red	—	—	—	—	40	35,973	3,270	4,032	366.5	8.92	10.56
,, 13	14	,,	5′ 6″	50	6	,,	5.90	482	17.00	260	40	47,021	3,358	5,488	392.0	8.50	11.00
,, 14	14	,,	5′ 0″	50	6	,,	4.86	(900° F.)	15.95	(500° F.)	40	46,636	3,331	4,928	352.0	9.46	11.20
,, 15	14	B ,,	6′ 0″	50	6	,,	6.00		14.06		40	44,580	3,184	4,928	352.0	9.00	10.60
					(about ¼ inch)						(108° to 109° F.)						

mounting used in these cases, and also as applied by Mr. Wilson (who supplies the illustrations) to boilers at Messrs. Tangye's works and elsewhere.

Other results of gas-firing will be found noted in Trans. Mining Inst. of Scotland, vol. vii. pp. 57 and 162, and in the Report of Mr. D. K. Clark to the Committee of the Smoke Abatement Exhibition (published by Smith, Elder & Co., London).

The following is extracted from the Report of a trial made by Mr. D. K. Clark on November 19, 1886, with four Cornish boilers at Hemel Hempstead, fitted with two 4-cwt. Wilson gas producers for generating steam by gas firing:—

"The boilers were each 5½ feet in diameter, with a 3-feet furnace tube, and 21 feet long, having eight Galloway tubes in each.

"The producers stood side by side in an open yard adjacent to the boiler-house. Each producer was cylindrical, 8 feet in diameter, 9 feet high, of firebrick cased in plate iron. The gas was conducted by an underground conduit to the boilers, where the supply of gas to each boiler was regulated by means of a valve. The gas was delivered through the doorway, together with air, into the furnace tube, where combustion took place.

"The four steam boilers were set in a row. No. 1 boiler was separated from the rest, and was devoted to the generation of steam for supplying the blast injector attached to each producer. The three remaining boilers were connected for the supply of steam to the factory.

"The quantity of steam consumed specifically for the creation of blast was thus measurable in terms of the feed water consumed by No. 1, whilst the quantity of steam generated by Nos. 2, 3, and 4 similarly could be measured.

"The coal consumed in the producers was cobbles from Wyken Colliery, broken up by hand, and charged into each hopper four times per hour.

"For the purpose of the test, which lasted five hours, the coal supplied to the producers was weighed, and the feed water supplied to No. 1 and to Nos. 2, 3, and 4 together, was measured separately. The level of the water in the boilers was maintained at the same height at the end of the trial as at the commencement.

"The leading results of the test are given in the following Table, and for the sake of comparison the results of a six days' test which had previously been made with hand-firing are prefixed. In this case, the fire-grates were 4 feet 8 inches long, presenting an area of 14 square feet for each boiler.

HAND FIRING *versus* GAS FIRING.

Date of trial	Sept.—Oct. 1886.	Nov. 19, 1886.
Kind of trial	Hand Firing	Gas Firing.
Kind of boilers	Cornish.	Cornish.
Number of boilers in steam	4	4
" " full steam	4	3
Duration of trial	142 hours.	5 hours.
Description of coal	Wyken cobbles.	Wyken cobbles.
Average pressure of steam per square inch	57.25 lbs.	55 lbs.
Average temperature of the atmosphere	—	52° F.
	tons. cwts. qrs. lbs.	tons. cwts. qrs. lbs.
Coal consumed	41 6 1 11	1 14 2 15
" " per boiler in full steam	10 6 2 10	0 11 2 5
" " " " per hour	163 lbs.	258.6 lbs.
" " per square foot of fire grate	11.64 feet.	
Temperature of feed water	54°	57½°
Water evaporated by boilers in full steam	8,476 c. feet.	374.02 c. feet.
" " " " per hour	59.69 "	74.80 "
" " per boiler in full steam	2,119 "	124.67 "
" " " " per hour	14.93 "	24.94 "

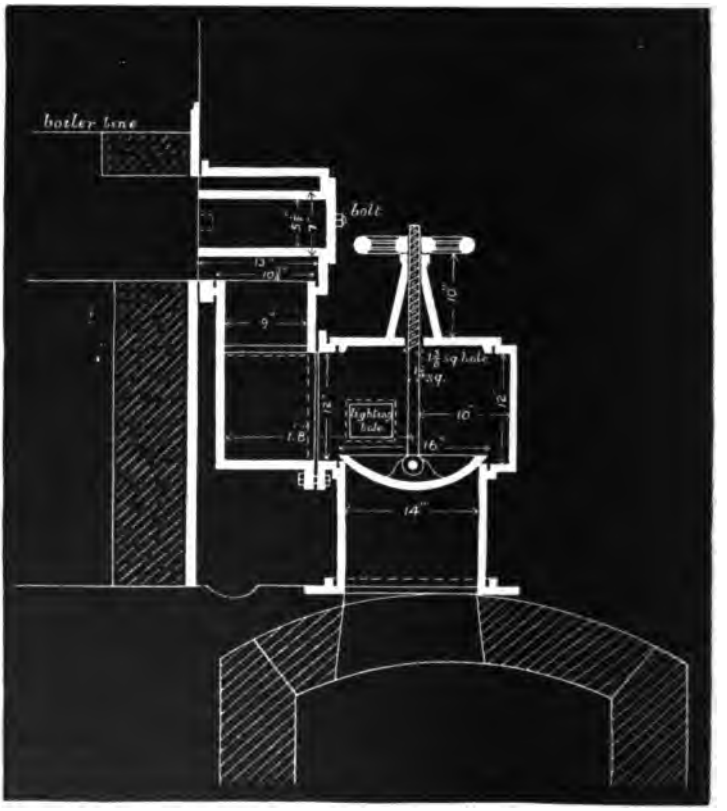
HAND FIRING *versus* GAS FIRING—(*continued*).

	Hand Firing.	Gas Firing.
Water evaporated by No. 1 boiler (producer) .	—	33.80 c. feet.
" " " per hour .	—	6.76 "
Total water evaporated by four boilers . .	—	407.82 "
" " per hour . . .	—	81.56 "
Water evaporated per lb. of coal . . .	5.71 lbs.	6.56 lbs.
Net " " by 3 boilers in full steam, exclusive of steam for producer .	—	6.02 lbs. net.
Ditto ditto from and at 212° . .	6.79 lbs.	7.16 "

"The following data may be re-stated for comparison :—

Coal consumed per boiler in full steam per hour	163 lbs.	258.6 lbs.
Water evaporated per boiler in full steam per hour	14.93 c. feet.	24.94 c. feet.
Water per lbs. of coal from and at 212° F. .	6.79 lbs.	7.16 lbs. net.

FIG. 423.



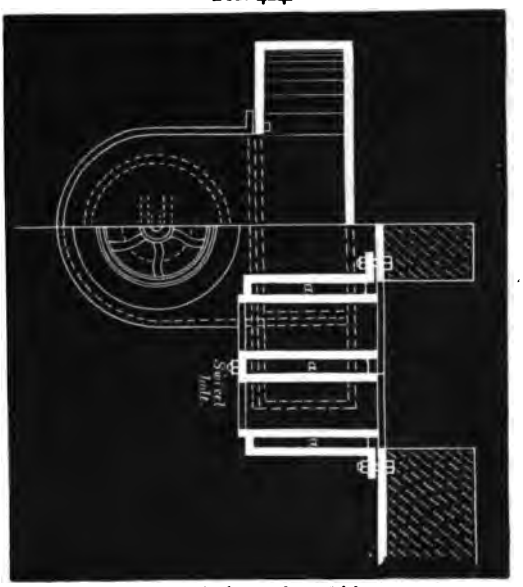
Elevation in section of gas-firing arrangement adopted first by Gadsden & Co.

"It is shown that the boilers in full steam did two-thirds more evaporative duty by gas firing than by hand firing, and with 5½ per cent. more evaporative efficiency, after allowance made for steam consumed in blowing

the producers. It is also shown that the weight of steam consumed by the producer is $\frac{33.80 \times 100}{407.82} =$ 8.29 per cent. of total quantity generated in the four boilers.

"The total evaporative efficiency of the boilers with gas firing, if no deduction be made for the demands of the producers, is expressed by 6.56 lbs. of water per lb. of coal, on an equivalent of 7.81 lbs. from and at 212°, which is 7.81 – 6.79 = .98 lb., or 14.4 per cent. more efficiency than was obtained by hand firing. This is an expression of the absolute difference of efficiency in favour of gas firing. The practical difference after making the needful allowance is, as above stated, 5½ per cent.

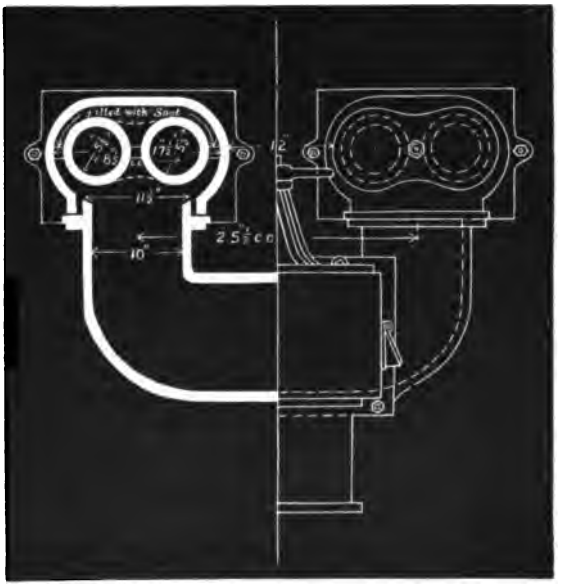
FIG. 424.



Plan partly in section of Fig. 423.

"Smoke was frequently visible at the top of the chimney during the trial with gas firing, ranging from No. 1 to 7 of the smoke abatement scale.

FIG. 425.



Front elevation—partly in section—of Fig. 423.

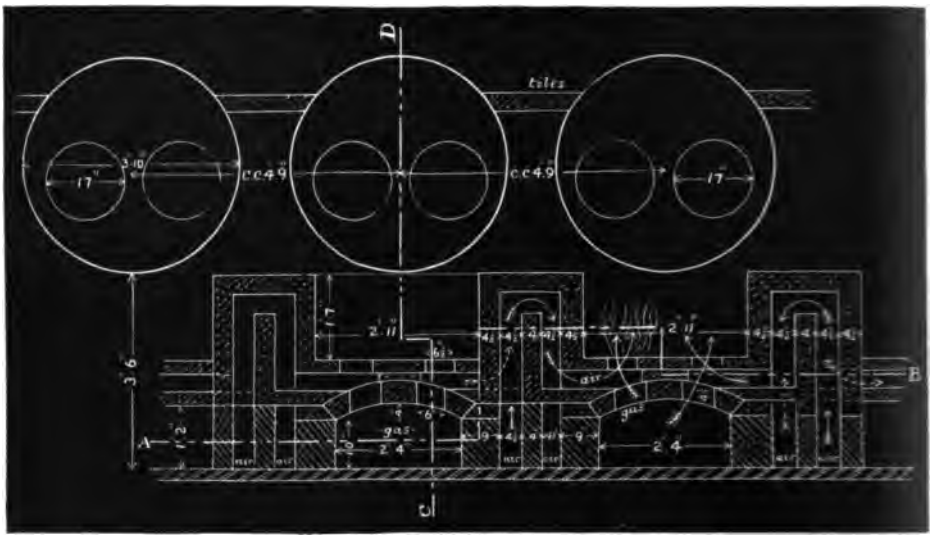
"This was evidence of deficiency of air, or of imperfect mixture of the air and the gas. In fact the furnace doors of Nos. 2, 3, and 4 boilers were 2½ inches open for the whole time to make up the proper supply of air. I should add that the attendant on the gas firing complained that he had to force the fire in order to keep up the pressure of steam. He called attention to the smallness of the back flue of the boilers.

"At intervals, of course, no smoke was visible with gas firing, and there is no reason why, under fitting conditions, gas firing should not be conducted entirely without smoke.

"Although the results of the comparative trials prove so far as they go

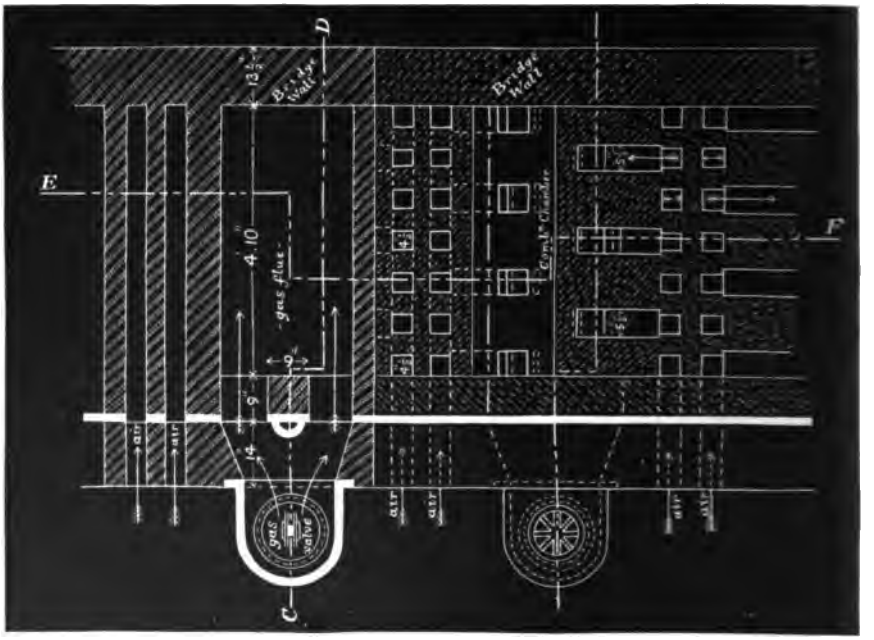
in favour of gas firing against hand firing, yet they are not quite conclusive, as the experimental boilers were evidently not worked under the most fitting conditions for either hand firing or gas firing. Considerably more

FIG. 426.



Section at *EF*, Fig. 427.

FIG. 427.



Section at *AB*, Fig. 426.

than 14.93 cubic feet of water should have been evaporated per hour in each boiler, and a greater evaporative efficiency than 5.71 lbs. of water per lb. of

coal should have been shown. At the same time, it is probable that with fitting conditions the gas firing also would have exhibited greater efficiency.

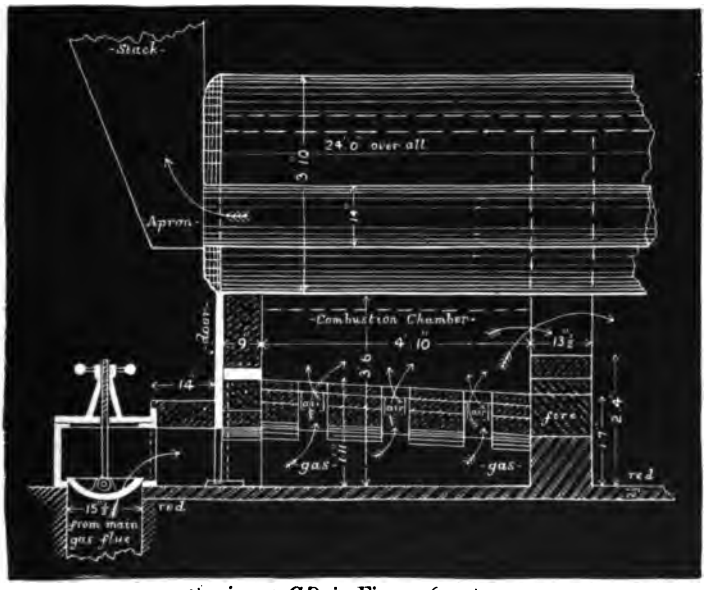
"On the whole, I am disposed to accept the percentage of advantage in favour of gas firing ascertained by the comparative trials, namely, an absolute difference of 14.4 per cent., or a net difference of 5½ per cent. in favour of the gas firing.

"This deduction fully harmonizes with the best result of Mr. J. H. Darby's experiments at Plas Power Colliery, which shows a greater absolute efficiency of 9.85 per cent. in favour of gas firing, or a net efficiency fo 4 per cent. in its favour.

"Looking to the evidence of greater evaporative efficiency and a greater rate of production of steam, it appears that the Wilson system of gas firing is worthy of a more extended trial.

"In estimating the pecuniary saving by its adoption, the cost of maintenance of the two producers may be taken at 10 per cent. per year on the

FIG. 428.



Section at *CD*, in Figs. 426 and 427.

first cost = £300. Against this, with interest on the capital, is to be set off the saving in cost of fuel and its attendance."

In the trials referred to previously as having been conducted in America by Mr. Dixon, under Messrs. Gadsden & Co., there were "eight boilers, each 24 feet 6 inches long by 3 feet 10 inches diameter, with two return flues each 17½ inches diameter, all connected by steam and feed drums, over one continuous grate 41 feet long by 6 feet broad, with eight firing doors. The flame, after passing under the boilers, returns through the flues, a brushing in front connecting them with stacks in pairs. The heating surface by American formula amounted to 3,300 square feet, and the effective surface, according to rules in Box's Treatise on Heat, about 2,100 feet.

"The consumption of coal by hand firing was about 5,400 lbs. per hour, with an evaporation of about 25,500 lbs. of water per hour, or less than 4¾ lbs. per lb. of coal, and about 12 lbs. per square foot of effective heating surface.

"Four producers were first applied, burning between 1,600 and 1,700 lbs. of coal per hour, the gas and air being admitted to the boilers by iron burners as shown in Figs. 423, 424, and 425 (pp. 566, 567). With the four producers clean and working well, the evaporation amounted to 14,500 to

FIG. 429.

Section at *AB*, Fig. 430.

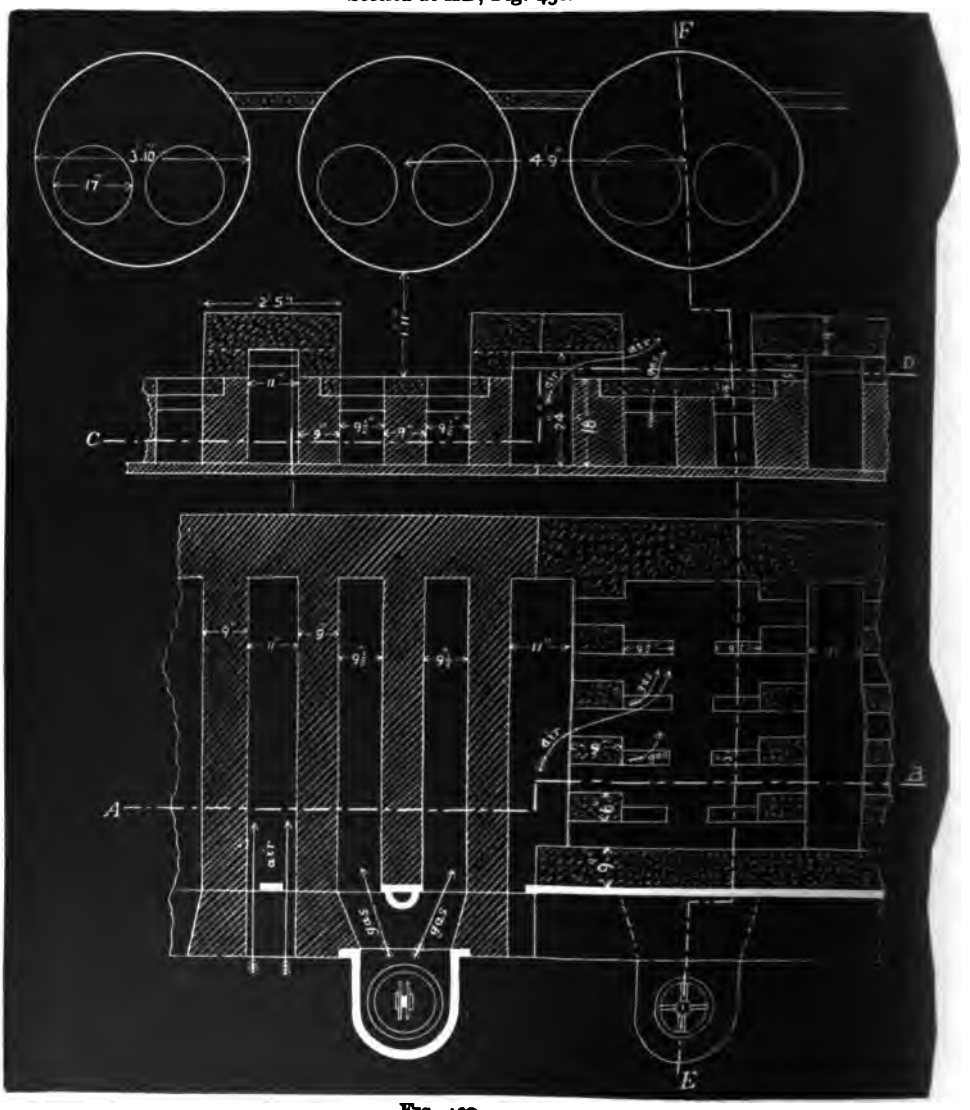


FIG. 430.

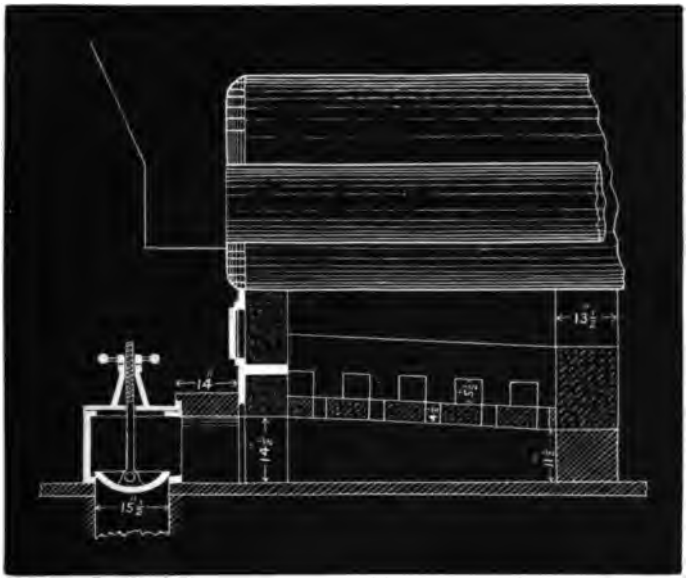
Plan in section at *CD*, Fig. 429.

15,000 lbs. per hour, or say 8⅓ lbs. of water per lb. of coal, or *7 lbs. for* each square foot of effective heating surface.

"Three more producers were added, first with the same *combustion* arrangements, and afterwards with those shown in Figs. *426, 427, and 428*

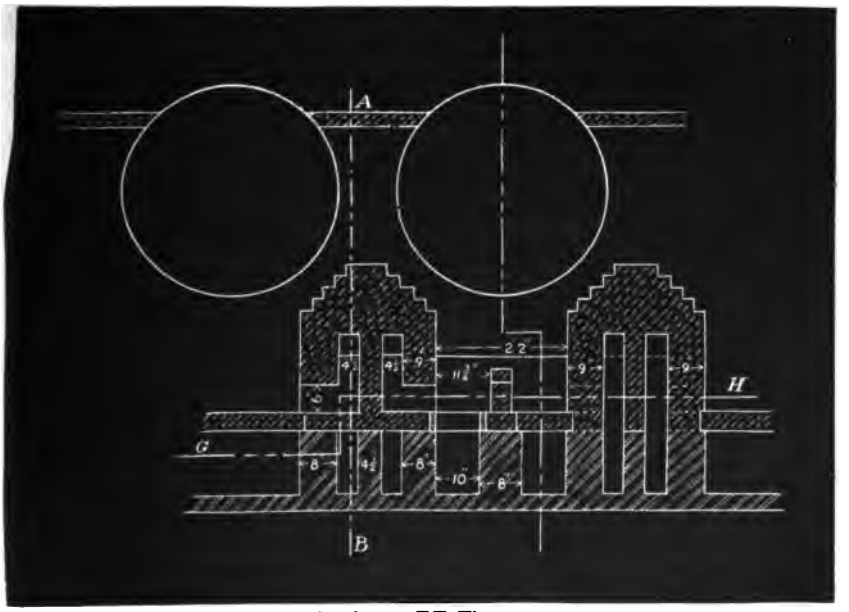
(pp. 568, 569), which was subsequently modified by alterations shown in Figs. 429, 430, and 431, and finally in accordance with those shown in Figs. 432,

FIG. 431.



Section on line *EF*, Figs. 429 and 430.

FIG. 432.

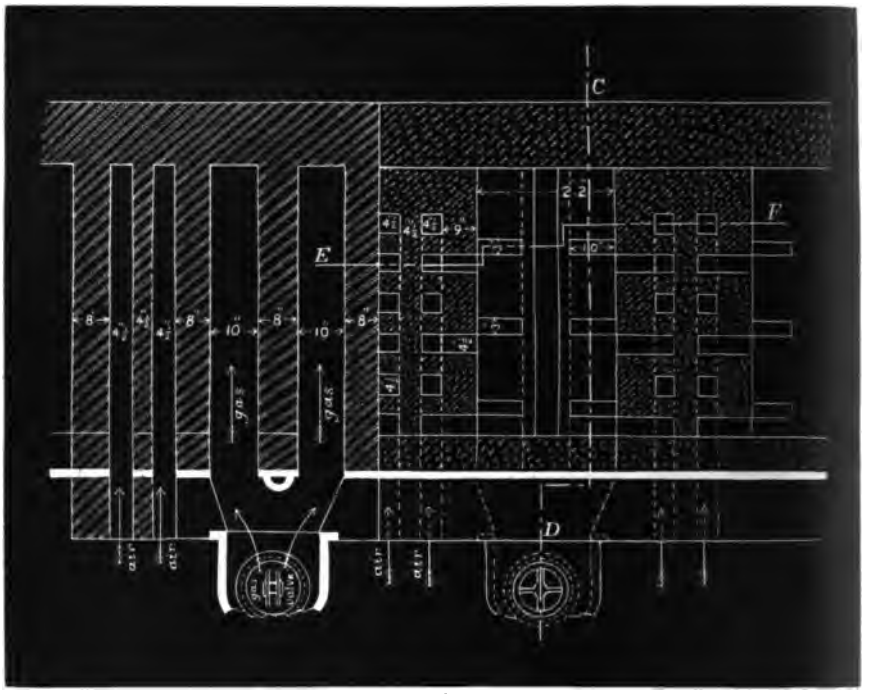


Section at *EF*, Fig. 433.

433, 434, and 435; but, with the seven producers working full, the greatest evaporation obtained was 20,000 lbs. of water per hour. An eighth

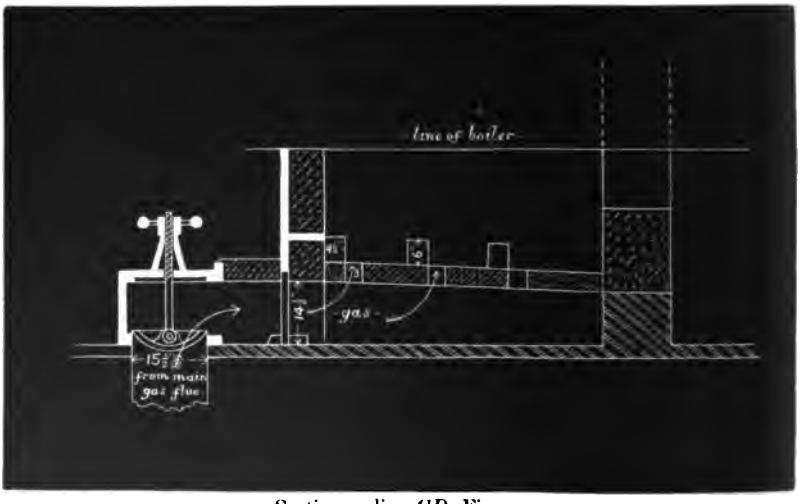
producer was finally added, but it was found that there was no additional evaporation by the combustion of the additional quantity of gas. In fact,

FIG. 433.



Plan in section on line *GH*, Fig. 432.

FIG. 434.

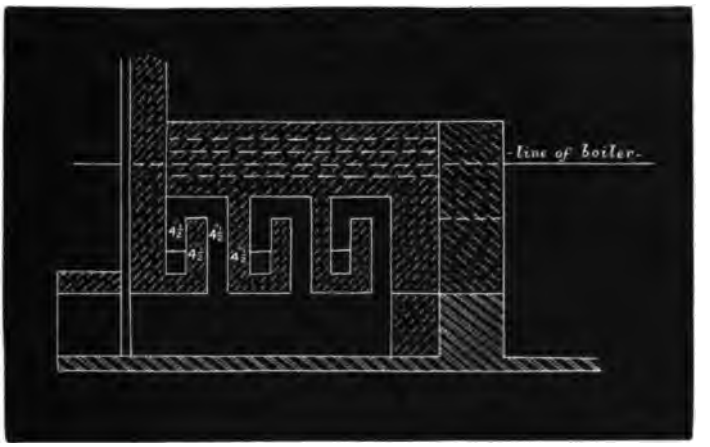


Section on line *CD*, Fig. 433.

six producers gave as large a result as seven, whilst more steam per lb. of fuel was obtained when working four producers."

Mr. Dixon remarked as follows on these results, as compared with those given in Mr. Darby's Report :—" Darby's Report confirms the conclusions I have drawn. Observe that in his trial No. 1, 750 lbs. of coal per hour were

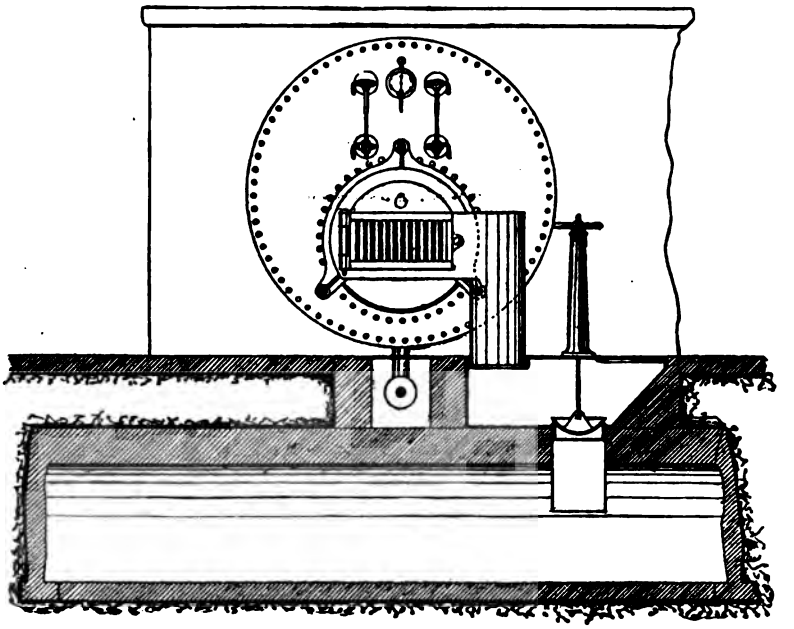
FIG. 435.



Section on line *AB*, Fig. 432.

consumed, or nearly 2 lbs. for every square foot of effective heating surface, and only 5.8 lbs. of water per lb. of coal. In trial No. 3, only 438 lbs. of

FIG. 436.

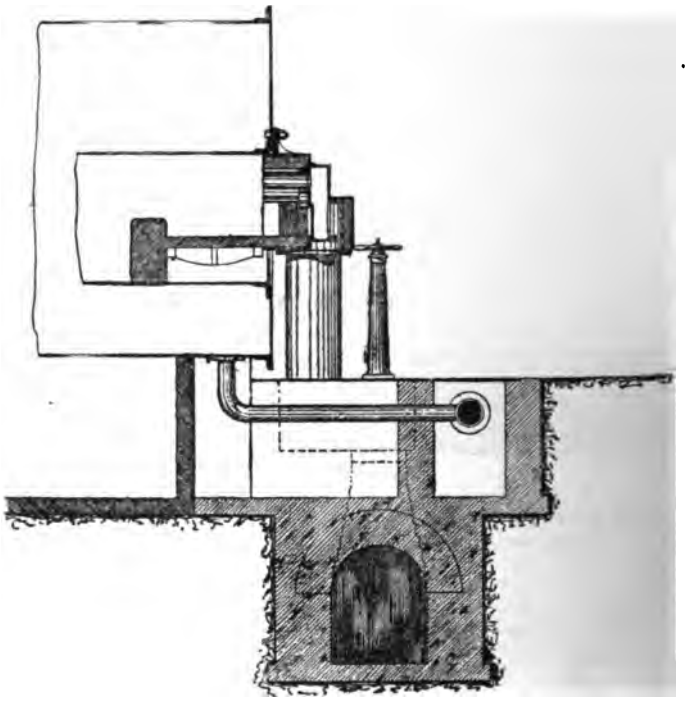


Elevation of single-flue boiler arranged for gas firing—Gas flue in longitudinal section.

coal were consumed per hour, less than 1 lb. for each square foot of heating surface, and 8.6 lbs. of water per lb. of coal, which is very fair. In the

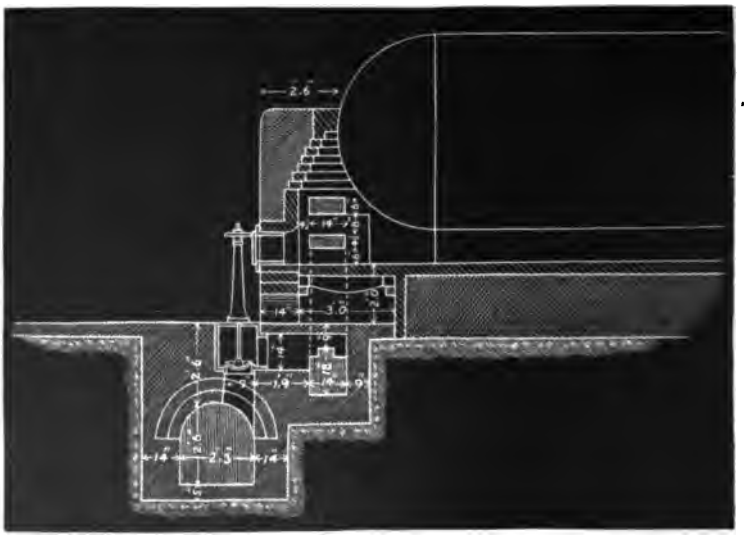
first instance, at considerable expense of gas, he succeeded in getting each effective square foot to evaporate nearly 10 lbs. per hour. In the latter, the

FIG. 437.



Section of single-flue boiler arranged for gas firing—Gas flue in cross section.

FIG. 438.



evaporation was 8½ lbs. per square foot per hour, which is more than a

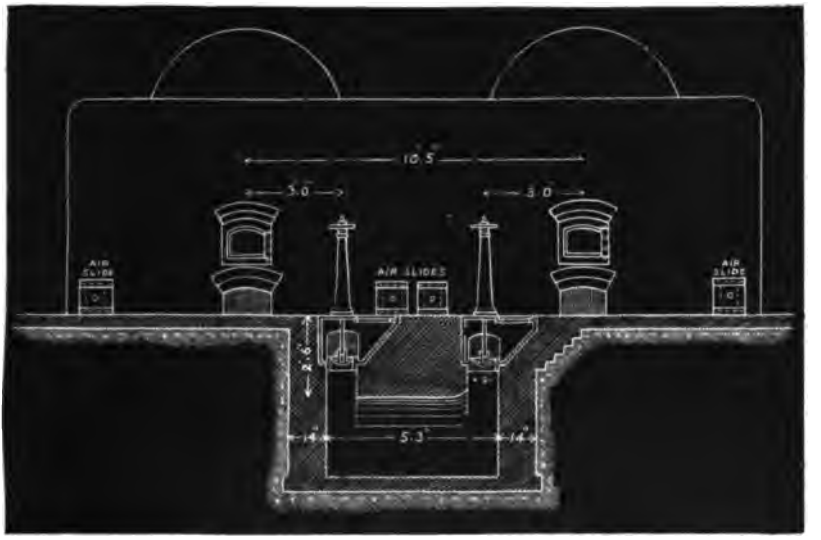
boiler should be called upon to do. Had the consumption of fuel been reduced to ½ lb. per square foot, or 220 lbs. per hour, the evaporation would probably have been 10 lbs. of water per lb. of fuel, or 5 lbs. per square foot of surface per hour, which is the economical point.

"In our trials, our first, with four producers, was nearly equal to Darby's third and best; whilst our worst, as far as economy of fuel was concerned, with eight producers was but little under his first. Our not being able to properly control chimney draught would account for the difference in both cases."

Some interesting results of the application of natural gas to boiler firing are given by Mr. A. Carnegie in his paper on Natural Gas in the Journal of the Iron and Steel Inst., vol. i. 1885, p. 174.

In order to illustrate the application of gas to different forms of boilers, Figs. 436 to 446 are added, Figs. 438 to 440 showing the method of firing egg-ended boilers, and Figs. 441 to 446 showing an added brick combustion chamber outside the boiler flues for Cornish or Lancashire boilers.

FIG. 439.



The only other plan to which we shall here refer, on account of its great interest, is that of the gas-fired boilers at the Engineering Works of Messrs. David Rowan & Son in Glasgow. At first, one boiler was tested with gas firing against a similar boiler alongside fired by hand, and comparative results were thus obtained. Both were subsequently fired by gas and continue to be worked on that system. The boilers are constructed of steel, each 10 feet 6 inches long by 8 feet 6 inches diameter, and contain eighty-two tubes of 4 inches external diameter, extending from end to end of the boilers. The tube surface is 901 square feet, and the area of shell which is exposed to heat is 133 square feet, the total heating surface being thus 1,034 square feet. With hand firing, there were 33 feet of grate area, whilst with the producer there are 15 square feet; so that formerly the ratio of heating surface to grate surface was 31 to 1, whilst with gas firing it is 69 to 1.

Originally the flues were arranged in the hand-fired boiler so that the flame and hot gases returned from the back of the boiler to the front directly through the tubes, and then were conducted along the sides to the

FIG. 440.

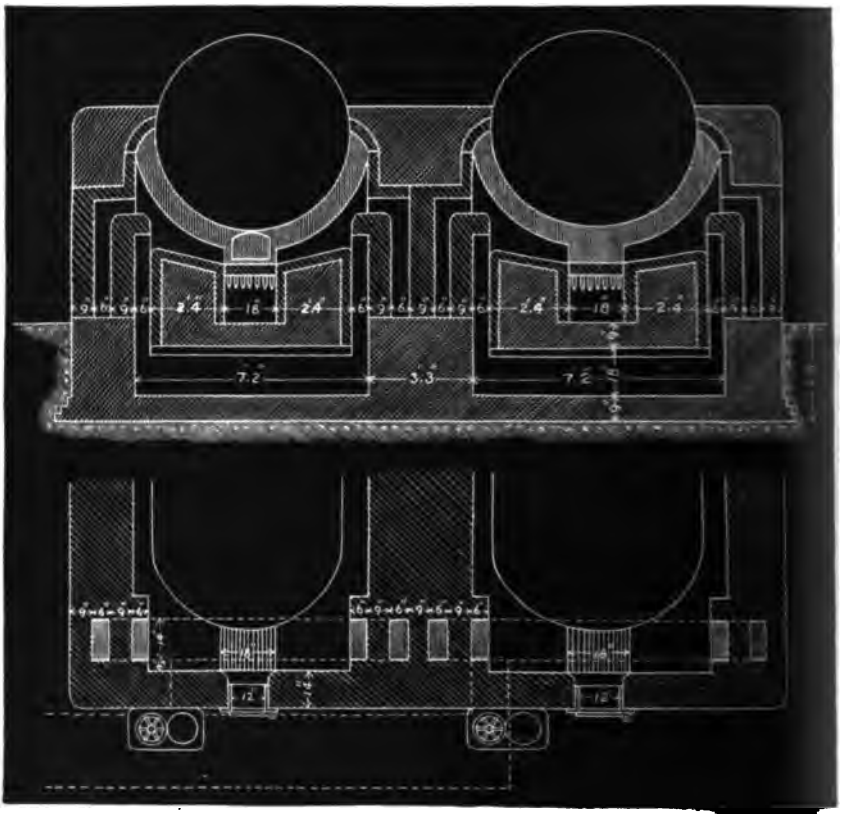
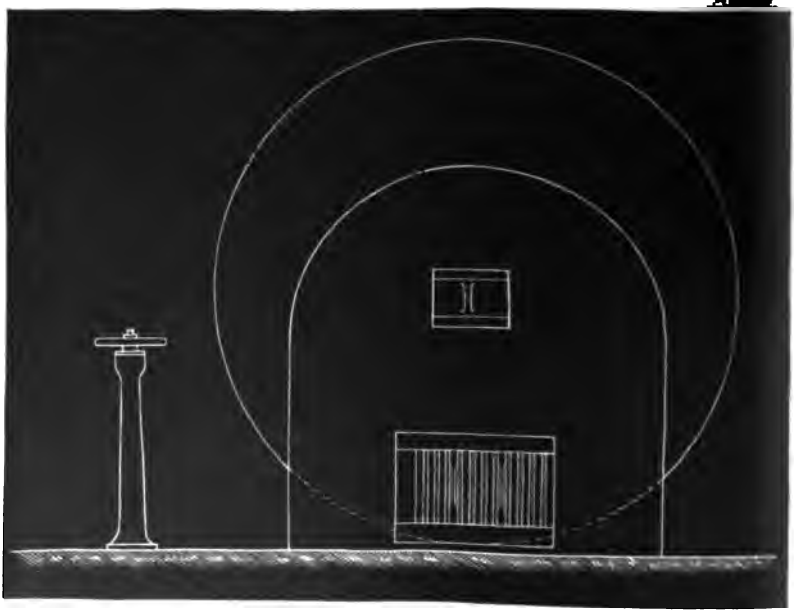


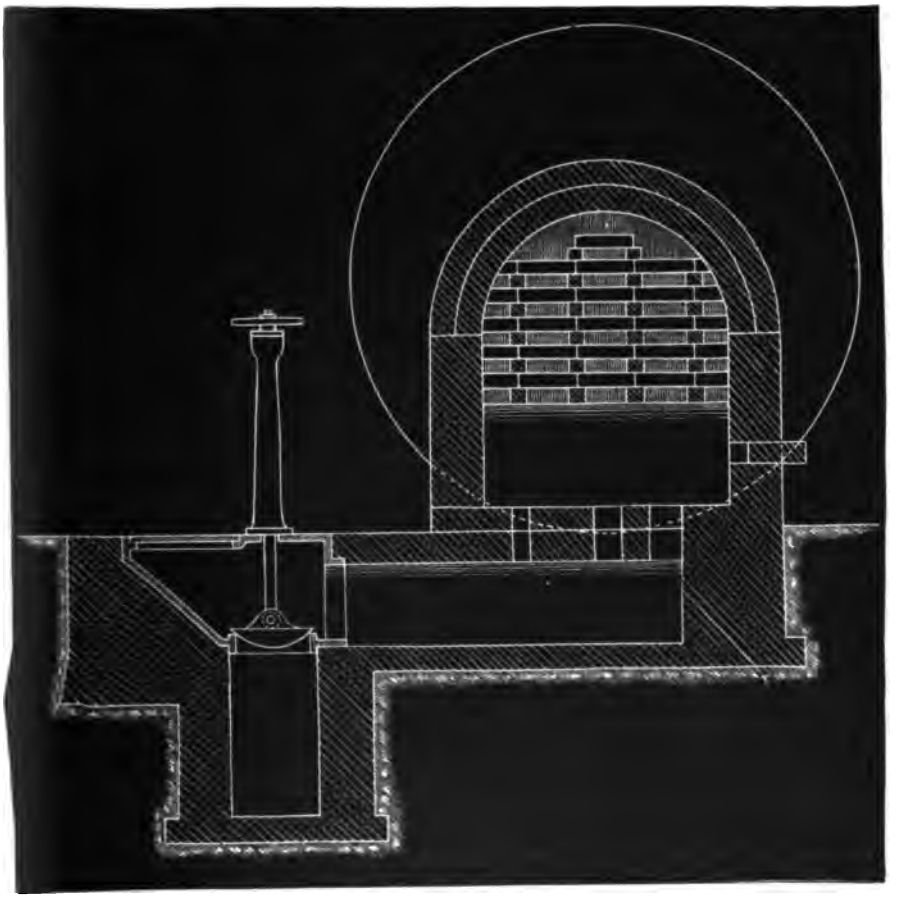
FIG. 441.



chimney-flue at the back. As thus arranged, a week's trial gave 5.651 lbs. of water per lb. of coal as the evaporative rate. The course of the hot gases was altered by causing them first to return to the boiler front by the side flues and finally to reach the chimney flue by the small tubes, and the result of this alteration was to raise the evaporative rate to 7 lbs. of water per lb. of coal. It was found that in the old arrangement the tubes extinguished the flame, and that a large quantity of unconsumed gas escaped to the chimney which, with the altered arrangement, was able to burn in the side flues.

By means of experiments made with boiler tubes placed over a jet of

FIG. 442.



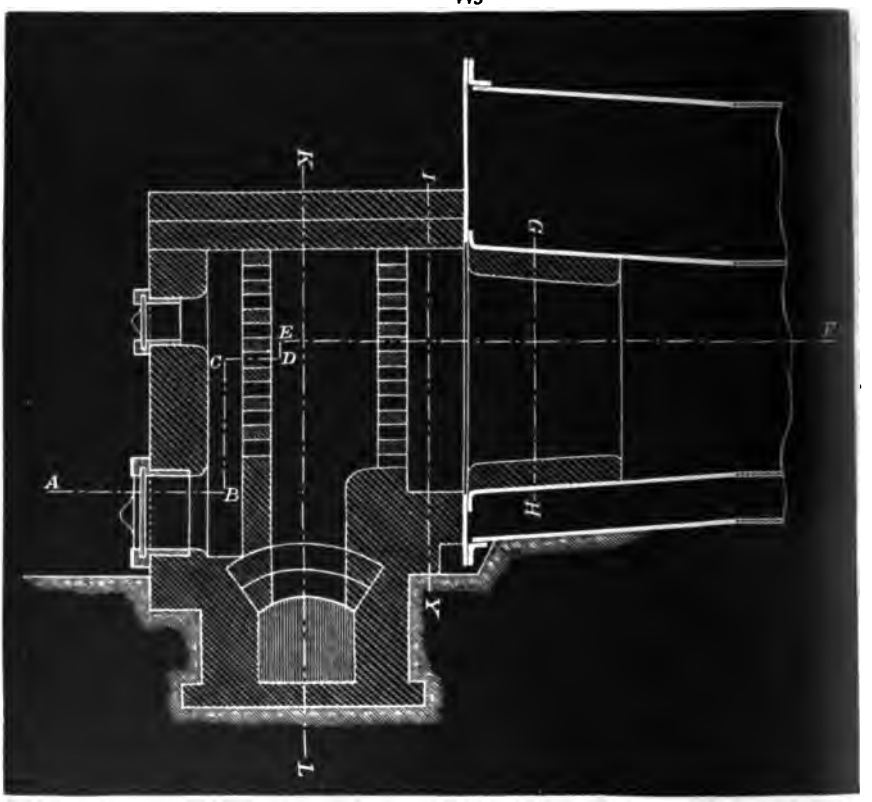
crude gas from a Siemens producer, Mr. W. Anderson found that 6 feet was the maximum length which a boiler tube of 3 inches diameter should have if combustion were intended to go on in it. It is probable that Mr. Anderson used vertical tubes, which might be expected to give a better result than the same tubes in a horizontal position. In Messrs. Rowan's boiler, the tubes were horizontal, so that in spite of their slightly larger diameter the extinguishing effect may have occurred within Mr. Anderson's limit of length.

In the gas-firing arrangement, gas is generated in a rectangular pro-

ducer 5 feet by 4 feet, the grate surface being 15 square feet, and the coal being kept at a depth of 2 feet to 2 feet 6 inches on the bars.

Air is supplied from a Root's Blower to the ash-pit of the producer, which is closed by an air-tight door, and the gas is led from the producer over an inverted arch to the under side of the boiler, where it meets a supply of heated air. Ignition here takes place, and the flame passes along under the boiler, returns along the side flues, and thence through the tubes to the chimney-flue. In order to heat the air for combustion, there are twelve rows of fire-brick tubes, 3 inches internal diameter, placed in the bottom of the boiler setting and heated there by radiation from the combustion chamber, and the air from the blower is directed through these—

FIG. 443.



first through five and then back through seven—to the combustion space, where it meets the hot gas from the producer.

The opening for escape of the gas from the producer to the combustion chamber is about 48 inches by 3 inches, or 144 square inches, which, with 15 square feet of grate surface, is nearly 10 square inches of opening for every square foot of grate. This, Mr. James Rowan, who described this plan to the Graduate section of the Inst. of Engineers in Scotland, considered to be a good proportion, as the gas was not restricted in its escape by the opening being too small; and, on the other hand, the producer and chamber were not turned into an ordinary air-furnace by the opening being too large.

The surface of the arch occasionally collects a deposit of tarry soot,

Fig. 444.

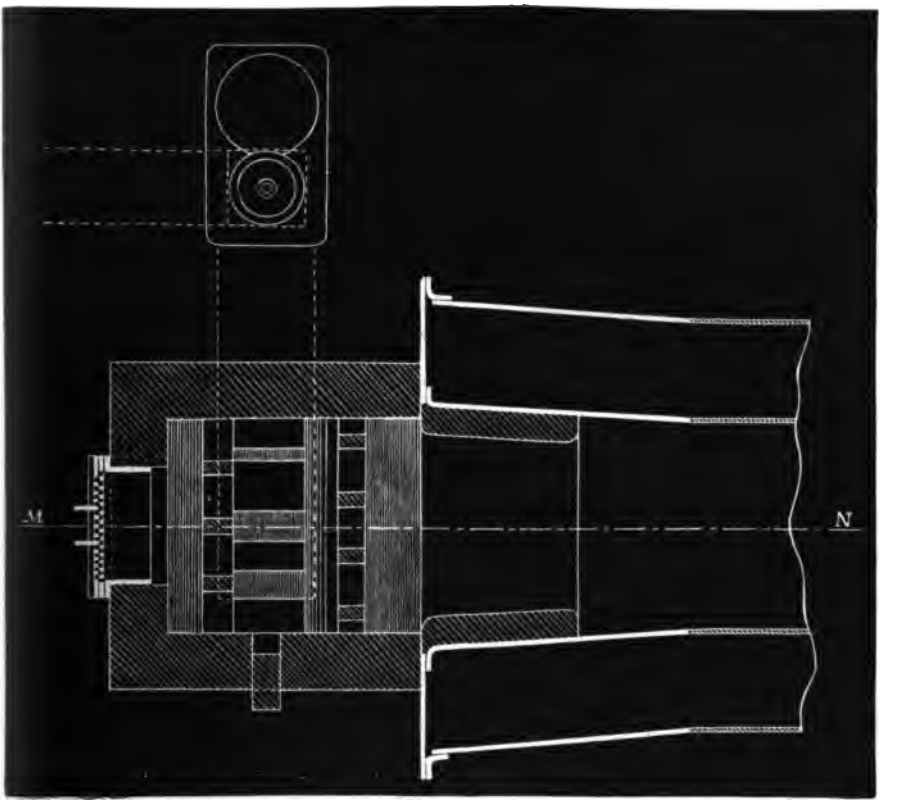
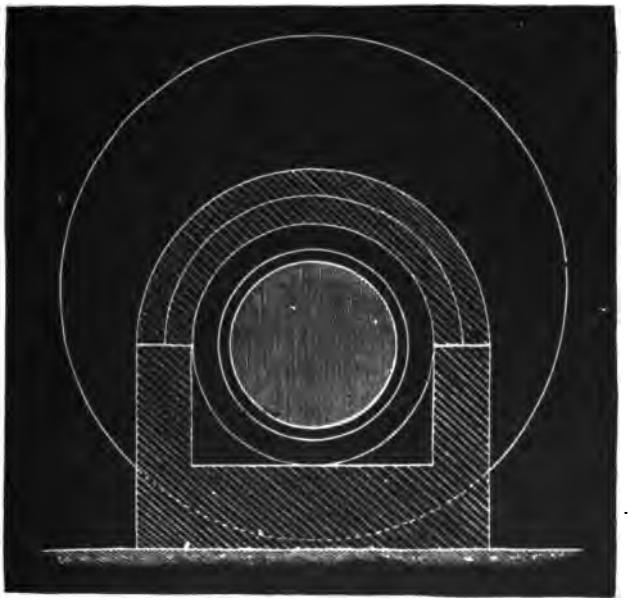
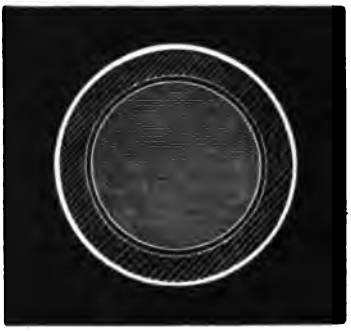


Fig. 445.



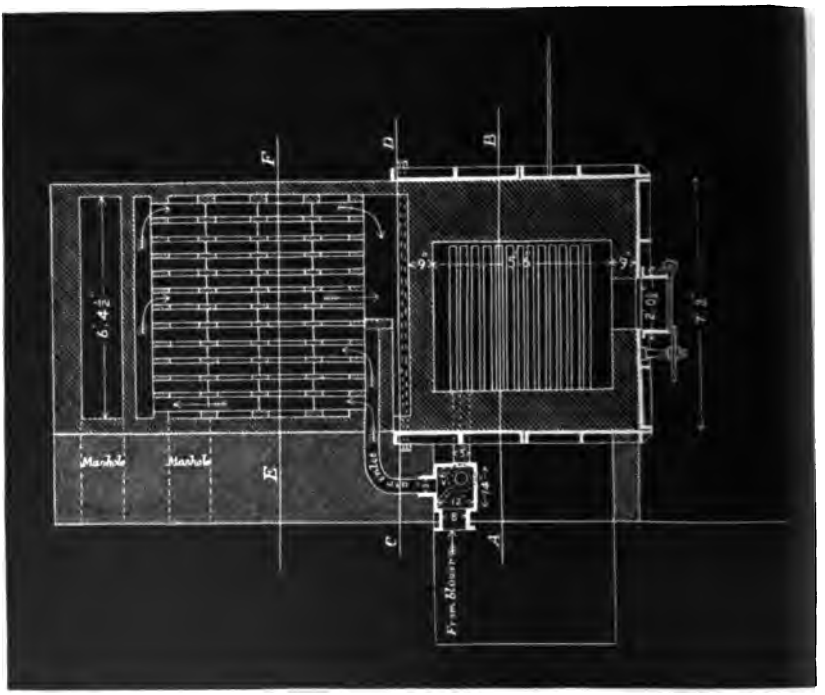
which is, however, easily cleaned off; and, except just at the period of charging fresh fuel, the process is entirely smokeless. The charging is carried out by hand through the firing-door shown in the illustrations, but there is no reason why a hopper with bell-cone, or similar arrangement, should not be used. This has the advantage of preventing the ingress of cold air to the producer, or of allowing the escape of much gas.

FIG. 446.



The evaporative results obtained with this arrangement were, in one trial, 9½ lbs. of water evaporated per lb. of coal consumed; and in another, which extended over three days, using a good quality of splint coal, 10.8 lbs. of water were evaporated per lb. of coal burned. The latter trial was made simultaneously with the trial of hand firing referred to, when 7 lbs. of water were evaporated per lb. of coal, the same quality of coal having been used for both boilers. It thus

FIG. 447.



appears that the gas-fired boiler evaporated 51 per cent. more water per unit of coal burned than the hand-fired boiler.

The following are the total quantities of coal used and water evaporated by the gas-fired boiler in the first trial referred to, which lasted from 1 P.M. on February 11, 1882, to the same hour on the 18th of that month. The quality of coal used was ordinary "tripping" or unriddled coal, from the Hamilton coal field. During the trial the engine was working for 58 hours.

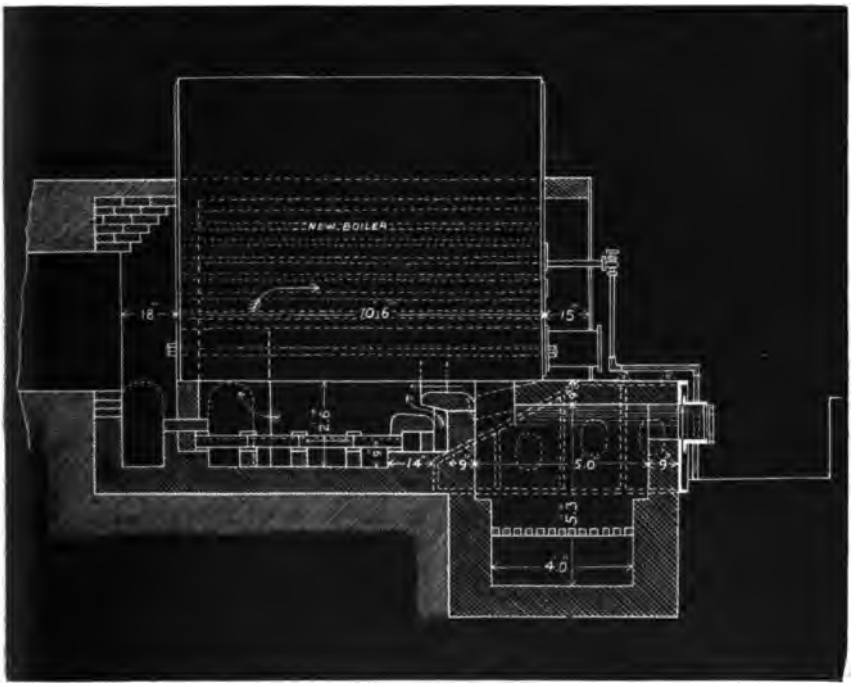
Water evaporated . . . 185,123 lbs.
Coal burned . . . . 19,488 lbs.
= 9.499 lbs. of water evaporated per lb. of coal burned.

This arrangement of Messrs. Rowan's is shown in Figs. 447, 448, and 449, Fig. 447 being a plan in section, Fig. 448 a longitudinal elevation in section, and Fig. 449 cross-sections on different vertical lines on Fig. 447.

Boutigny proposed the following arrangement for raising steam :—

Noticing that all bodies, solid or liquid, evaporate only by means of their surfaces, and taking advantage of this fact, he proposed to employ a cylinder the bottom of which was semi-spherical, and the top tightly screwed down, to which the usual accompaniments of a steam-boiler were attached—viz., steam- and feed-pipes, man-hole, safety-valves, steam-gauges, &c.

Fig. 448.



The cylinder contained from five to seven tin-plate diaphragms with the edges turned up; they were alternately convex and concave, pierced with small holes from below upwards.

The water, before arriving at the bottom of the cylinder, where it assumed the spheroidal form, had passed over a great surface, falling as a fine rain from one shelf to another, collecting in the one towards the centre, and in the next towards the rim.

The arrangement for collecting the steam between the two last shelves, tended to maintain the whole interior at the same temperature, and to produce steam of any degree of tension.

The cylinder was heated alone for a few minutes, after which a small quantity of water was admitted, and in twenty or twenty-five minutes more the apparatus was ready for work.

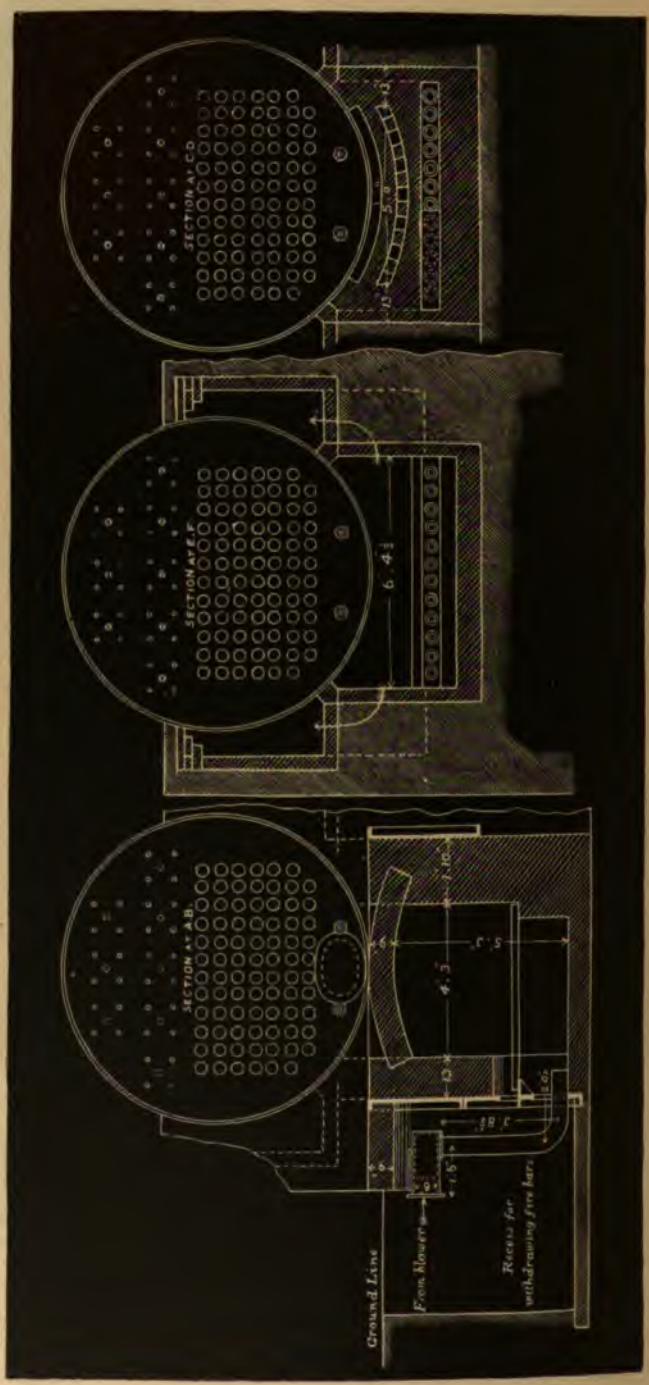

SECTION AT C.D.
SECTION AT E.F
SECTION AT A.B.
6' 4"
4' 3"
6' 5"
Ground Line
From Blower
Recess for withdrawing fire bars

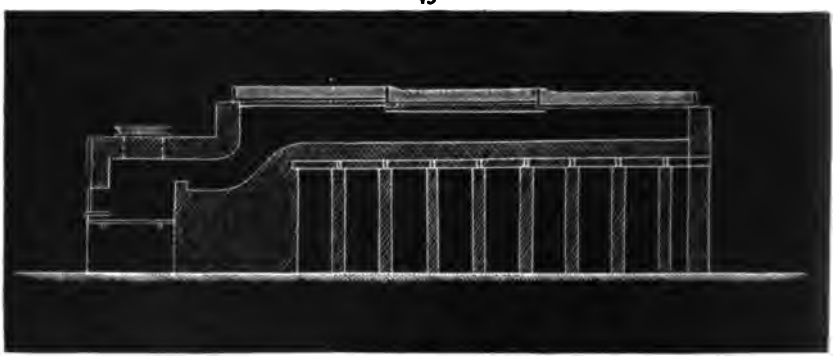
FIG. 449.

place at all temperatures, it proceeds much more rapidly as the heat increases and it has been proved both by calculation and experiment that less fuel is required to evaporate a given weight of liquid at the boiling point than to evaporate the same weight at any lower temperature. The general practice, however, is to employ a much larger heating-surface in evaporating vessels than is usual in steam boilers, and the smoke and hot gases are cooled down as much as is compatible with a good draught before escaping to the chimney. There is no economy of fuel in using very deep evaporating vessels, as the quantity of liquid evaporated, for the same amount of fuel consumed, depends on the extent of surface exposed to the fire or source of heat, and the rapidity of convection.

When evaporation takes place at the boiling temperature, the rate of evaporation will not be materially affected if the vessel be closed, with the exception of a sufficient aperture for the escape of the vapour; but there is always a loss of heat if the exposed surface of the cover is not itself covered with some non-conducting substance.

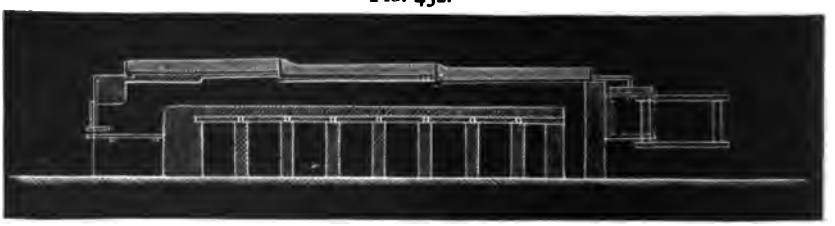
The open pans employed in concentrating oil of vitriol are shown in Figs. 451, 452, which are from sketches supplied by Messrs. C. Tennant

Fig. 451.



& Co. Fig. 451 shows a sectional elevation of lead evaporators utilizing the spent heat from a furnace, over the fire-place of which is a platinum pan for concentrating the acid. The lead evaporators prepare the acid for running

Fig. 452.



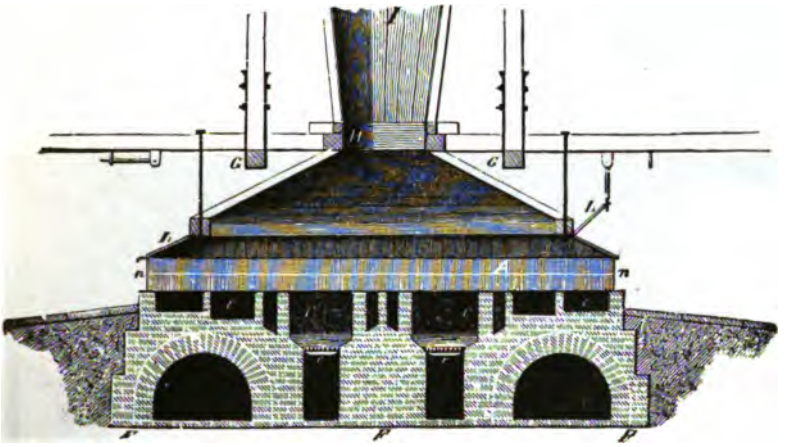
into the platinum pan. Fig. 452 shows lead evaporators for concentrating acid up to 1.70 sp. gr.

The fall of the pans is from the fire-place instead of towards it, as was customary some years ago, this having been found to work better and more economically, the strong heat of the fire being required to drive off the water from the weak acid, while the spent heat finally concentrates the stronger acid.

Surface evaporation in close furnaces, as described below, is the plan adopted in some large vitriol works in this country.

The large shallow pans employed in evaporating brine for the production of salt are shown in Fig. 453, and the arrangement of the flues conveying the smoke and hot gases in Fig. 454. These pans are flat quadrangular vessels, constructed of sheet-iron, often 60 feet long by 30 in

Fig. 453.



breadth, and by the arrangement of the space below them, the flame from the two furnaces is brought into contact with the entire bottom surface of the pan. In order to increase the rapidity of the evaporation, the pan is nearly covered by a large wooden funnel, opening above into a vapour-

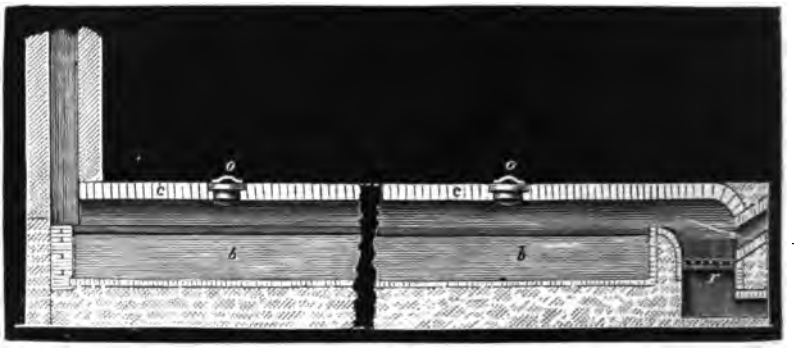
Fig. 454.

chimney *I*; the lower part of this hood or funnel is constructed of planks, which can be turned up so as to admit the air freely to the surface of the liquid from the side opposed to the wind. The vapour has sometimes been carried into the chimney instead of escaping by a separate funnel; but when

it is produced in considerable quantity, the draught is liable to derangement. This is likewise the case when the vapour is conveyed to the ash-pit. In some localities, large drying-flats for prepared chalk or whiting are connected with these salt-pans, so as to employ the waste heat.

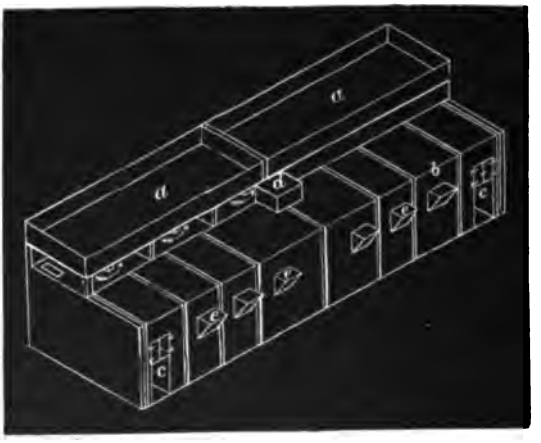
Where it is necessary to concentrate large quantities of weak liquors, which are of such a nature as not to be injured by the products of combustion and the particles of dust and carbon they carry with them, the flame and heated gases may be carried over the surface of the liquors. This plan of surface-evaporation is practised with weak alum-liquors, as shown in Fig. 455. It was originally adopted in consequence of the sediment which

Fig. 455.



is deposited during the process attaching itself to the bottom of the ordinary open pans, and causing their rapid destruction. These tanks are constructed of bricks, cemented together with a mixture of lime and lixiviated alum-shale. They are very shallow, but of great length, so as to offer an extensive surface to the current of hot air and gases. An open pan is sometimes placed above them, which serves as a feeder for the lower pan.

Fig. 456.



Allied to these are the evaporators forming part of the incinerators used in paper works for the recovery of the waste soda lyes. Amongst the more important of the plans in use are the incinerators of Arnot and of Porrion; whilst a very promising system* of applying gas firing to incinerators has been introduced at some works in England with undoubtedly good results.

Fig. 456 represents a pan-furnace for boiling down liquors to dryness, where the material is not injured by an excessive temperature. The interior of the furnace is lined with sheet-iron, or rather consists of a long sheet-iron pan, capable of holding 2,000 gallons of liquid. The fires *c c* are at each end, the steam and products of combustion passing off by a flue *d*.

* See British Patent specification, No. 7859—1886.

The working doors *e e e* project in front of the furnace, and facilitate the removal of the dry mass. The open pans *a a* are heated by the waste heat of the pan-furnace *b*.

Hot or cold air, driven by a fan or other machinery over the surface of a heated liquid, is a powerful evaporating agent, and its efficacy is much increased by agitating the liquid with a rouser, so as to bring as large a surface as possible into contact with the current. The plan of forcing heated air through liquids to be evaporated, which was at one time extensively practised in sugar factories, has been entirely discarded, as not economical and frequently tending to alter the nature of the liquid.

Evaporation of Brine by Gas.—In the salt works at Ischl, the plan of heating up the brine in open pans by means of waste steam was discontinued on account of its taking up much room and producing a rough discoloured salt. It also required special attention, and has consequently fallen into disfavour in several localities.

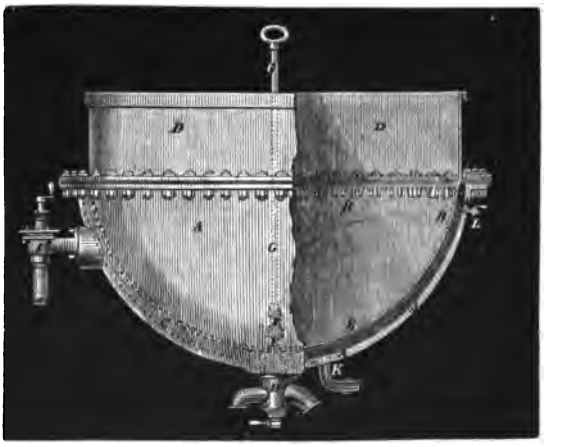
At Ischl,* special vessels, made of sheet-iron strongly rivetted, are used for heating the brine, and are combined with automatic apparatus for regulating the feed of the liquid. These vessels are rectangular in shape, but narrow and high, and are grouped together by the arrangement of pipes for feeding and discharging.

The heating is carried out by producer gas, which is burned with heated air in a combustion chamber used for directly drying the salt. The combustion must necessarily be complete in order to prevent discoloration of the salt, and the waste heat can be used for heating the brine.

It has been found that on burning Traunthal coal in the producer there was obtained on an average 137.3 kilos. of salt for every 100 kilos. of coal; whereas the ordinary method of firing yielded only 117 kilos. of salt, there being a saving in favour of the producer of 13 per cent. in fuel. When wood was used, the producer gave a saving of 14.8 per cent. of wood as compared with the old method of firing.

Evaporation by Steam.—Steam is employed to evaporate liquids which contain substances liable to be altered by exposure to a higher temperature than that of boiling water or of high-pressure steam. It is applied in two ways: either to the outer surface of the pan by means of a jacket, or to the interior by means of a coil of pipes. In both cases the extent of surface must be so calculated that the same amount of vapour shall be condensed by the heating-surface as is required to be expelled from the liquid to be evaporated.

FIG. 457.



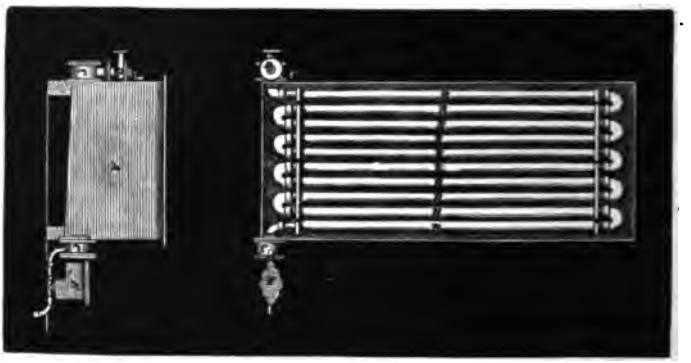
It has been calculated, that for evaporating vessels with steam jackets, every square foot of heating-surface will condense about 0.6 lb. of vapour per hour for a difference of temperature of 1° Centigrade; and a coil of pipe,

* See *Dingler's Polyt. Jour.*, 250 [8], 365-369; *Oesterr. Zeit. für Berg. u. Hüttenw.*, 1883; "Jour. Soc. Chem. Ind.," March 1884.

not exceeding 1 to 1.3 inches in diameter, for a length of 6½ to 10 feet, will condense 1.7 lbs. of vapour per square foot per hour.

The steam evaporator, or heater, with a double bottom, as employed in sugar factories, breweries, distilleries, and print works, is shown in Fig. 457. *A* is the outside jacket, composed of cast iron; *B* the inner copper pan; *C*

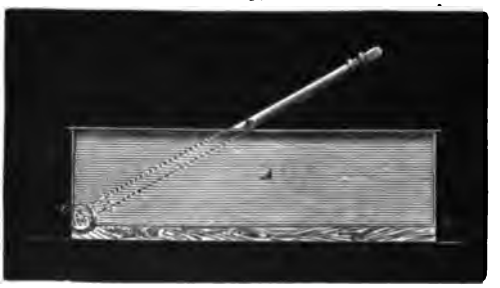
Fig. 458.



the space between them, into which steam is admitted by means of the valve at *I*; *K* the pipe for carrying off the condensed water; *L* is a small cock for allowing air to escape when steam is admitted to the pan.

Open steam evaporators, heated by pipes, are shown in Figs. 458, 459. They are large rectangular iron vessels, *A* containing a series of pipes *B B*, which work through stuffing-boxes *C*, and are connected together by gun-metal bends. The whole set of pipes can be raised at once, in order to be thoroughly cleaned, as shown in Fig. 459. Steam is supplied to the pipes by the valve at *D*, and the condensed water flows off into *E*.

Fig. 459.



Another method of evaporating weak liquors is shown in Fig. 460. Here the steam from a vacuum-pan is introduced into a series of straight copper pipes, placed one above another, their ends being fixed into cast-iron boxes. The steam is admitted through the pipe *D*, and passes in the direction indicated by the arrows, escaping finally at *E*. The weak liquors to be evaporated are allowed to fall in a fine shower from a perforated trough *B*, on to the heated pipes. A large surface of liquid is thus exposed simultaneously to the hot surface and to the air, and is concentrated while the steam in the interior of the pipes is condensed.

When it is desirable that the air should be totally excluded from the liquor to be evaporated, and that the evaporation should proceed at a temperature lower than that at which the liquid would boil when exposed to the atmospheric pressure, recourse is had to the vacuum-pan.

Fig. 461 represents this apparatus as employed in concentrating sugar-liquors; *L* is a vessel for regulating the supply to the pan, whilst the vessel *M* is intended for collecting any portion of the liquor which may accidentally boil over; *A* is an outer cast-iron jacket, between which and the inner copper vessel *B* steam is admitted; *D* is the copper worm, also supplied

Fig. 460.

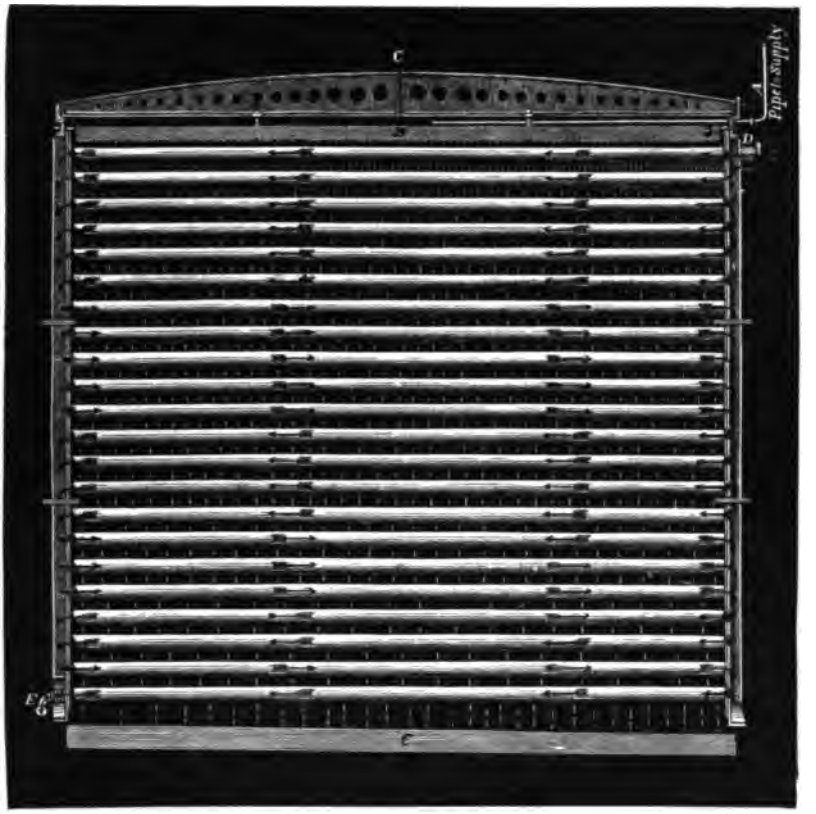
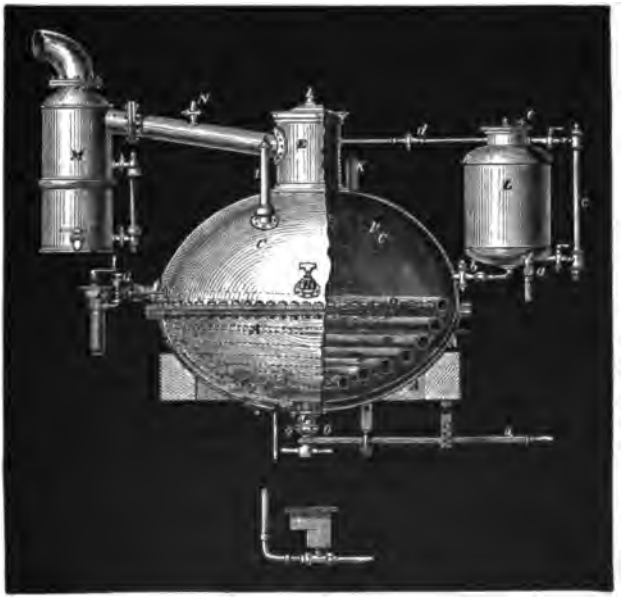


Fig. 461.



with steam from the valve *F*. The vapour is pumped off by an air-pump through *E*, which is assisted by the condenser shown in Fig. 375, or by some arrangement similar in principle. *I* is a thermometer for indicating the temperature of evaporation; *K* a barometer or vacuum-gauge, for ascertaining the pressure in the pan. The temperature at which the liquor would boil, under atmospheric pressure, is about 250° F., and it is reduced by the vacuum to 150° F. or less.

Evaporation by Multiple Effect.*—The value of steam as a heating medium has already been referred to (pp. 478–484), and the fact that the boiling point of liquids varies with the pressure has long been known and is the basis of the use of the ordinary vacuum pan. It is only within a comparatively recent period, however, that these principles have been taken advantage of in anything like a complete way in connection with the evaporation of liquids. The lowering of the boiling point of water by diminution of pressure is shown by the following Table:—

The temperature of water boiling at atmospheric pressure is		. . .	212° F.
,,	,, under 5 inches vacuum is	. . .	195
,,	,, ,, 10 ,, ,,	. . .	185
,,	,, ,, 15 ,, ,,	. . .	160
,,	,, ,, 20 ,, ,,	. . .	150
,,	,, ,, 25 ,, ,,	. . .	130
,,	,, ,, 26 ,, ,,	. . .	120
,,	,, ,, 27 ,, ,,	. . .	112
,,	,, ,, 28 ,, ,,	. . .	100
,,	,, ,, 29 ,, ,,	. . .	72
,,	,, ,, 29½ ,, ,,	. . .	52

Other liquids follow a similar rule, but have different normal boiling points; and even water, when containing sugar or other substances in solution, has its temperature of boiling at atmospheric pressure raised. It is apparent from these facts that if in several vessels there are different degrees of vacuum produced, we can have a descending scale of boiling temperatures, so that vapour of comparatively low temperature can be utilized as it is produced. "The different boiling points of a liquid under different pressures can thus be utilized, by making the vapour given off in boiling the contents of the first vessel at a certain pressure form the heating agent of the liquid boiling in the second vessel at a lower pressure, the vapour from this second vessel forming the heating agent in the third, and so on."

This principle was applied in what is known as the Rillieux system, and governs all forms of what are now called "Triple-effet" (or triple effect) apparatus. The Rillieux system utilized "the latent heat of the vapour of liquids boiling under a low vacuum to boil a second pan working under a higher vacuum. The usual limit to this system is four pans, thus utilizing the latent heat four times and reducing the fuel to nearly one-fourth of that required for open evaporation or single vacuum pans. As generally arranged, all the boiling liquids in the system are under a partial vacuum; the first under about 5 inches, from which the vapour is taken to boil a second under 12 inches vacuum; from this to a third, boiling under 19 inches vacuum, and from this to a fourth, boiling under 27 inches vacuum."

"In liquids liable to injury by heat, the total variation of temperature available under ordinary conditions is that between the temperature of steam at 5 lbs. pressure per square inch (227° F.) and the temperature of a solution at 30° Baumé boiling under a vacuum of 26 inches (131° F.)—a total of 96° F. With a triple effect (or three vessels), however, there is steam at 5 lbs. pressure in the drum or shell of the first effect, and the liquid in the tubes—at atmospheric pressure—boils at 227° F., giving off vapour at

* On Evaporation by Multiple Effect, by F. J. Rowan: "Jour. Soc. Chem. Ind.," 1889, vol. viii. p. 32.

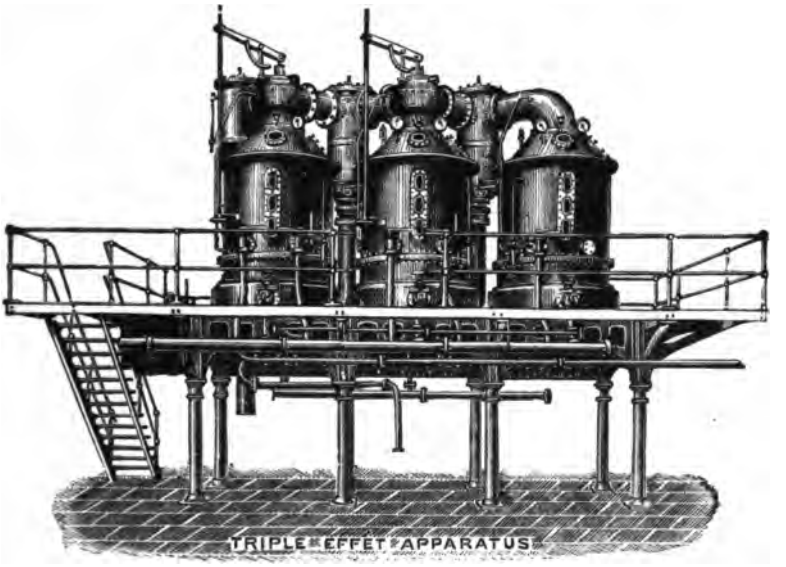
212° F. This vapour at 212° F. passes into the shell of the next effect and boils the liquid in the tubes of this effect under 14 inches vacuum, giving off vapour at 161° F. This again passes to the shell of the third effect and boils the liquid in the tubes under a vacuum of 26 inches, the boiling point of this liquid (supposing it to be a concentrated solution of 30° Baumé) being 131° F.

It is a point worth noting that where the liquid is a solution of solids in water, the vapour will always be at the temperature of boiling water at the pressure to which the liquid is subjected at the time, whilst the liquid itself will be warmer.

The total difference of temperature in evaporating liquids liable to injury by heat being, as mentioned above, 96° F., whilst the amount of heat transmitted through the tubes (and therefore the work done) is practically proportional to the difference in temperature, it is evident that the same work is done whether the whole of this difference is in one vessel or is subdivided among several vessels. In other words, a double, triple, or quadruple effect can only do the work of a single effect the size of the first vessel of the multiple effect; but it does it with $\frac{1}{2}$, $\frac{1}{3}$rd, or $\frac{1}{4}$th of the quantity of steam or fuel respectively."

Fig. 462 illustrates the arangement of triple effect apparatus manufactured by Messrs. A. and W. Smith & Co., of Glasgow. This apparatus

FIG. 462.



is generally composed of three vessels, which may be placed either vertically, as shown in the illustration, or horizontally. Each of the vessels has a calandria, or tube-chamber, filled with small brass tubes, in the lower part of the vessel. The steam, which under ordinary working conditions is merely the exhaust steam from the engine connected with the apparatus, is admitted to the lower part of the chamber surrounding these tubes and acts upon the liquor inside the tubes, the level of the liquor being three-fourths of the height of the chamber. The steam or vapour rising from the surface of the liquor in this first pan enters into the tube chamber of the second pan and boils the liquor in it. The steam or vapour from the surface of the liquor in the second pan enters the corresponding tube-chamber of the third pan, and boils the liquor which it contains. The vapour from this

pan is drawn through the condenser by means of a vacuum pumping-engine, which acts on the other pans also.

In its normal working it will be observed that the steam admitted into the first chamber is the actual heating medium for the three vessels. The apparatus is generally fitted with isolating valves, so that any of the pans can be thrown off at pleasure.

The temperature is highest in the first pan and lowest in the third; whereas the quality of the vacuum is arranged in the reverse order, it being highest in the last pan, which is nearest to the condenser and vacuum pump. This distribution of temperature and vacuum is said to be well suited to the evaporation of sugar liquor. The pans are fitted with eye-glasses, gauge-cocks and other appliances necessary for the manipulation of the liquor from one pan to another, and for testing its consistency during evaporation. The whole apparatus is generally mounted on a cast-iron framework composed of columns and girders in order to render it accessible.

Although in the form of apparatus just described, the liquor being evaporated is inside the small tubes, and the steam used for heating it is outside, in the triple-effet apparatus as ordinarily arranged, the reverse order has usually been maintained.

The influence of the highly ingenious Yaryan apparatus has doubtless been felt in this and other details, but the action of the Yaryan evaporator is sufficiently distinct to demand separate description. The great objections found to exist against multiple-effect apparatus as usually constructed are the high temperature to which the liquor is exposed in the first vessel, and the length of time which is required to treat the volume of liquid contained in it. In the manufacture of sugar with the ordinary triple effect the heat of the first effect, which reaches to nearly 200° F., combined with the long time to which the liquor is subjected to it, is a fruitful source of "inversion" of the sugar. With the Yaryan system, however, frequent tests with the polariscope demonstrate that there is no inversion, and consequently no loss of sugar from that cause.

The Yaryan Evaporator.—The ingenious invention of Mr. Homer T. Yaryan, of Toledo, Ohio, U.S.A., has met with a very large measure of success from its first introduction in America in 1886, and has in large measure superseded all previous attempts to produce economical evaporation by machinery. Mr. Yaryan adopts in his apparatus the two principles of "Evaporation in a Vacuum" and "Evaporation by Multiple Effect." The evaporator itself consists of a series of straight tubes, passing from end to end of a shell or drum, and coupled together by an ingenious arrangement of "pockets" to form coils, the main advantage gained by this design being the great ease with which the straight tubes can be examined or cleaned. As a rule, the coils consist of an odd number of tubes, the inlet being at one end of the evaporator and the outlet at the other. At the outlet end of the evaporator is a separating chamber, in which the liquid discharged from the tubes is completely separated from the vapour. Below the separating chamber is a "collecting chamber" into which the liquid flows, whence it is drawn, by the superior vacuum, into the vaporizing coils of the second effect, in which it undergoes a second process of evaporation by means of the vapour which comes, through the vapour pipe at the top of the separating chamber of the first effect, into the shell of the second effect.

This principle of "multiple effect" can be repeated in the Yaryan to an almost indefinite extent, its limit being gauged only by the commercial aspect of the question.

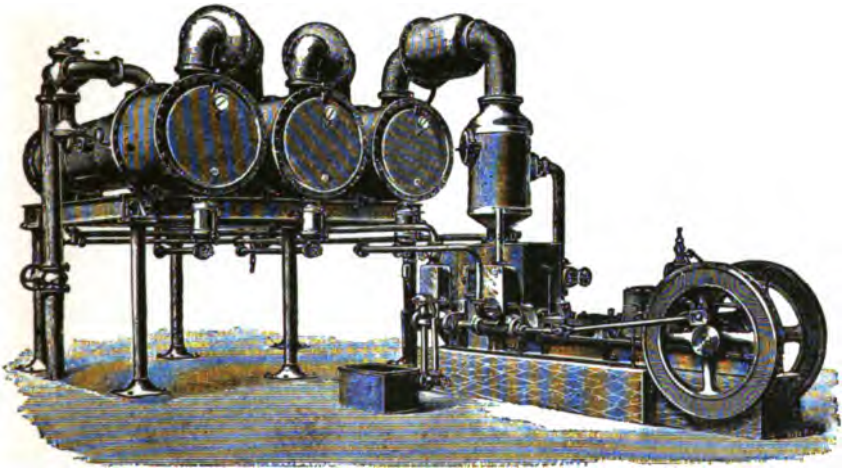
The vaporization in the Yaryan apparatus differs from that which occurs in previous systems in that it takes place in the interior of the above-mentioned vaporizing coils, the heating agent being outside the tubes; and

as the rate of the feed of liquid to be evaporated is arranged so that it cannot fill these coils, there is never any depth of liquid to be displaced by the vapour in its endeavour to escape from the heating surface. In addition to this, the rapid circulation induced by the formation of the vapour in the interior of the tubes, promotes a movement which brings into play the whole of the heating surface in a manner which has never before been effected. Tests taken from Yaryan evaporators in operation have shown an evaporation per square foot of heating surface more than double that of any evaporator previously invented, whilst by the new principle embodied in Mr. Yaryan's invention, evaporation by multiple effect can be carried further in his apparatus than in any other.

As an evidence of the practical results obtained by the Yaryan evaporator, over one hundred machines, with a daily evaporating capacity of over 3,000,000 gallons, and concentrating a variety of liquids, have been started during the last two years, and all are giving great satisfaction.

The applications of the Yaryan evaporator are very extensive, as the following list will show, the liquids named having all been successfully dealt with :—Solutions of sugar, glucose, glue, glycerine, beer worts, grape must, waste alkali liquors from paper mills, bark extracts, dyewood extracts,

Fig. 463.



tannin, liquid beef, pure caustic soda, tank waters from slaughter-houses, &c. &c.

It has also been applied to the concentration of milk and to the production of distilled water from sea or impure water. In fact, it can be applied to almost any liquid requiring concentration.

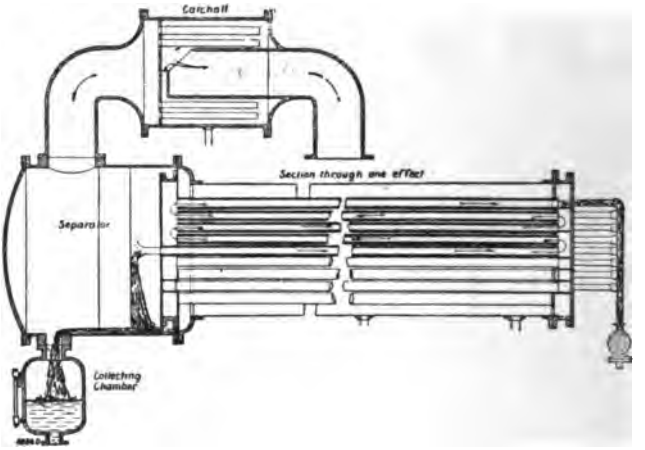
The general arrangement of the apparatus is shown in Fig. 463. As will be seen, it consists of three or more horizontal vessels mounted on a light staging. It is provided with a condenser and pumping engine for maintaining a high vacuum in the last pan, and the engine is also provided with small pumps for feeding the liquor into the first pan, and withdrawing it, after concentration, from the last.

The action of the apparatus will be understood from the diagram, Fig. 464, giving a simplified section through one of the pans and "catch-alls." The heating tubes, surrounded by steam, are divided into units or sections, known as "coils," and consisting of five tubes coupled at the ends so as to form one passage. One of these "coils" is shown in the illustration. Its

action may be taken as typical of that of all the coils in the pan, of which there may be any number proportional to the work to be done. The liquor enters the first tube of the coil in a small but continuous stream, and immediately begins to boil violently. It is thus formed into a mass of foam, which contains, as it rushes along the heated tubes, a constantly increasing proportion of steam. As the foam and steam cannot escape by the inlet end of the coil, and as steam is being continually formed, the mixture is propelled forward at a high velocity, and finally escapes from the last tube into an enlarged end chamber, known as the separator. This is provided with baffle plates, against which the mixture of steam and liquor impinges on issuing from the tube. The liquor falls to the bottom, whilst the vapour passes on to heat the next pan.

The arrangement described is said to give an almost perfect separation of the liquor and vapour; but to make doubly sure, and to avoid the chance of losing any sugar, the vapour is next passed through the special form of catch-all shown in the illustration. This is also a part of Mr. Yaryan's invention. Here the vapour is divided by tubes into a number of small streams, each of which impinges against the end wall of the chamber, giving up any drops of liquid carried over. The vapour itself escapes by the central pipe. This catch all is found in practice to prevent any detectable

FIG. 464.



loss even when used for liquors far more liable to foaming than those dealt with in sugar manufacture.

The advantages claimed for the Yaryan apparatus are many and important. The duty of each square foot of heating surface is twice that which can be obtained in apparatus worked in the ordinary method. There is only a small quantity of liquor in the apparatus at any one time, and the circulation is rapid and compulsory. These are both very important points, seeing that the action of heat on sugar is injurious in proportion to the time during which it is applied, as well as to the intensity of the heat. The apparatus is found in use to be practically automatic and requires the minimum of attention. It can be started and stopped in far less time than that needed with the older apparatus, which will contain hundreds or even thousands of gallons of liquor.

The economy of fuel realized in the Yaryan arrangement of multiple-effect evaporation is thus stated by the patentees. A well-proportioned steam boiler, fired with good fuel should evaporate 8½ lbs. of water per lb.

of coal. Each pound of steam condensed in the first effect will evaporate one pound of water, less the heat required to bring the liquid to be evaporated to its boiling point. If the initial temperature of the liquid were, say, 50° F., and the boiling temperature, say, 140°, there would be a loss of 90°. As there are about 966° of latent heat in steam, this loss would amount to nearly 10 per cent. Or, supposing the liquid is at the boiling point when it reaches the apparatus, every pound of steam condensed in the first effect evaporates 1 lb. of water, and in turn the vapour thus produced evaporates 1 lb. of water in the next effect, and so on. There is, of course, some loss by radiation of heat; but, as the vessels are small and easily lagged, this is reduced to a minimum: 16 lbs. of water will therefore be evaporated in a double-effect Yaryan apparatus, 23½ lbs. in a triple-effect, 30½ lbs. in a quadruple-effect, and 37 lbs. in a quintuple-effect for each lb. of coal burned under the boiler.

With the ordinary vacuum pan, or steam pan boiling, only 8½ lbs. of water will be evaporated per lb. of coal used, whilst with direct firing not more than 5 lbs. of water per lb. of coal can be evaporated.

Distillation.—The separation and collection of a more volatile ingredient of a mixture from others which are less volatile or more fixed, is called *distillation*. When the distillate is liquefiable, the operation may simply consist in raising the temperature of a mixture sufficiently to evaporate the volatile ingredient, and in condensing the volatile product, either to the liquid or solid condition; or it may involve the decomposition of the substance heated, and the condensation of the products of decomposition, when it is termed *destructive distillation*. The latter process is sometimes carried on for the sake of the volatile products, as in the manufacture of gas and gaseous combustibles. Where a solid body is thus treated and the products are liquid or gaseous, the process is called *dry distillation*, and is generally destructive. It is called *sublimation* when the product condenses from the state of vapour to the solid condition, without passing through the intermediate state of liquid.

The distillatory apparatus, or still, is constructed of brick, fire-clay, iron, copper, or platinum, according to the nature of the substances to be operated on. The escape-pipe for the vapour is generally large, as it is desirable that the vapour should leave the still with as little obstruction as possible. Air and water are almost the only agents employed for condensation, and the condensing-pipes are generally of iron or copper, except in those cases where corrosive substances are condensed, such as acids, when stone-ware pipes and receivers are employed, or, in the case of vitriol, when glass, platinum, and lead are used.

The dimensions of all the parts of the apparatus will depend on the quantity of vapour required to be produced and condensed in a given space of time, when the specific and latent heat of the products will necessarily form an important item in the calculations.

The still is generally heated by the direct action of the fire and flues; but steam, of high or low pressure, applied either to the outer surface, or by a coil of pipe to the interior, or by both conjointly, may likewise be employed as a source of heat. Either high or low pressure steam, or superheated steam, may be brought into direct contact with the substance to be distilled, where the products are of such a nature as to be easily separated from the condensed water; and lastly, the facility with which vapours rise under diminished pressure, renders distillation in a vacuum desirable in special cases.

The same general principles may be applied to the setting of stills over the fire as those which are applicable to boilers; the larger the heating surface exposed the better, provided that a good draught is secured and the

contents are not liable to be burned by the direct action of the fire on the material of the still. This, however, is frequently the case, as in the preparation of spirits, where a rapid distillation is required; rousers frequently being employed to prevent the solid contents from adhering to the bottom of the still.

Fig. 465.

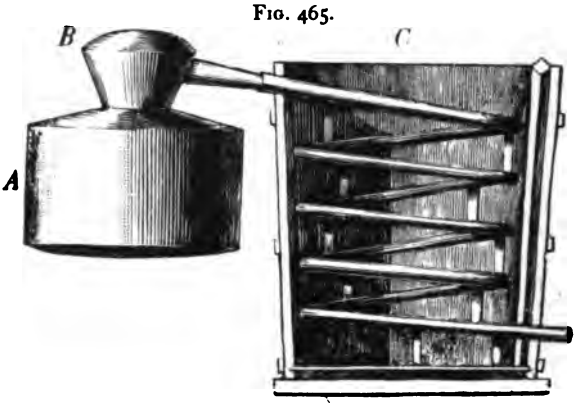


Fig. 465 represents the simplest form of still, with a worm-pipe condenser. *A* is the still; *B* the head; *C* the refrigerator, kept constantly supplied with cold water, and containing the worm for the condensation of the vapour. For ordinary purposes, the diameter of the still may be 2½ times its height, and the neck about ⅓ of the diameter. It may be set in the manner shown in Fig. 466, when the flame, after leaving the bottom of the still, separates at 2 into two flues, which enclose it on either side and meet again at 4, where they again branch into two upper flues, 5 5, before entering the chimney at 7.

Fig. 466.

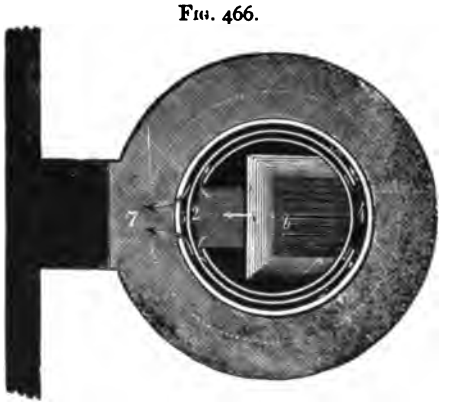


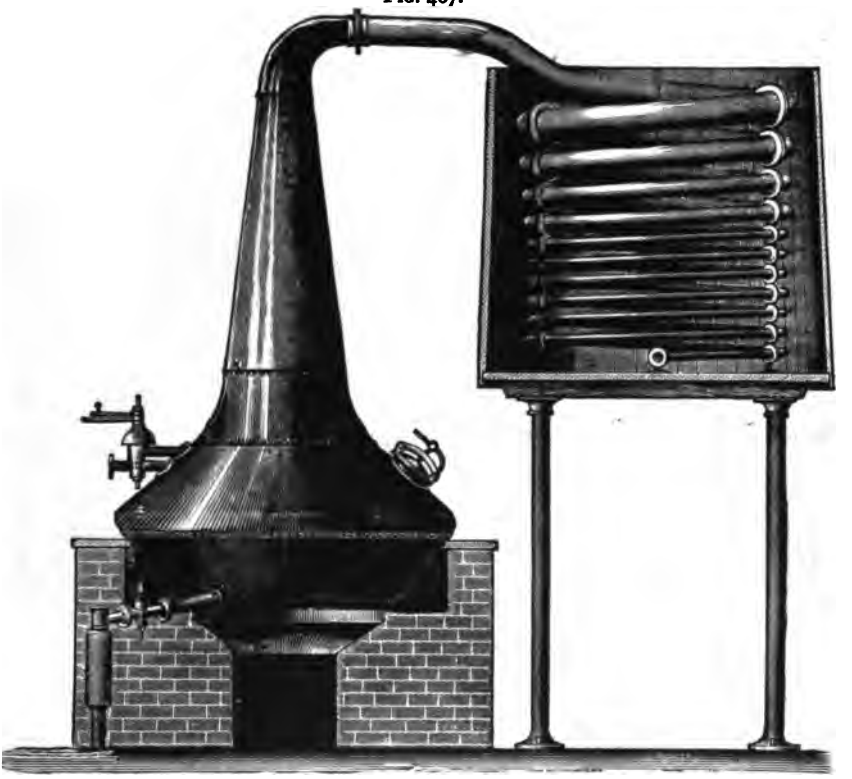
Fig. 467 illustrates a copper still (of a capacity of 1,556 gallons) of the old pot type, as it is now used by the distillers of fine malt whisky in the Highlands of Scotland. This still measures 9 feet 6 inches in diameter, and 19 feet high, and is set upon brickwork, with the openings for furnace door and flue not shown. This illustration is that of the still made by Messrs. John Miller & Co., of the Glasgow Copper Works, and shows their air- and charging-cock. This is an ingenious contrivance to prevent a vacuum being formed in the still when charging with cold liquor. A new and compact spent lees receiver is also shown, which the makers have designed to fulfil the requirements of the Inland Revenue authorities while occupying as little space as possible. The condensing worm of the old circular type is shown, this being still in great favour with distillers; but this construction shows a new arrangement of stays. The flanges on each section are made to serve the double purpose of joining up the separate pieces of the coil and also of supporting each other in position without the aid of wooden supports, which were found to have some drawbacks; and thus any piece can be taken out without disturbing the other parts of the coil.

The simple still continues in use for many operations in manufactories, but for the production of brandy, whisky, and spirits generally, where the product requires to be redistilled before it is sent into the market, a great saving of heat, and consequently of fuel, is effected by making the wash or

liquor condense a great portion of the vapour, which portion is returned again to the still, while the wash itself absorbs the latent heat. The vessel in which this is effected thus becomes a second still, or rectifier, and the product is finished in one operation.

Fig. 468 shows the apparatus invented by Dorn for this purpose. *A* is the still, heated by the direct action of the fire; *B* the head, from which a pipe *r* conveys vapour to a small refrigerator, for the purpose of testing the strength of the distillate; *E* is the ordinary condenser, containing worm, &c. The intermediate copper vessel answers two purposes; the upper part *c* forming a heater for the wash, whilst the lower compartment *D* acts as a rectifier. The heater *C*, when filled up to the level of the cock *m*, contains the exact measure of wash for charging the still; the contents can be con-

FIG. 467.



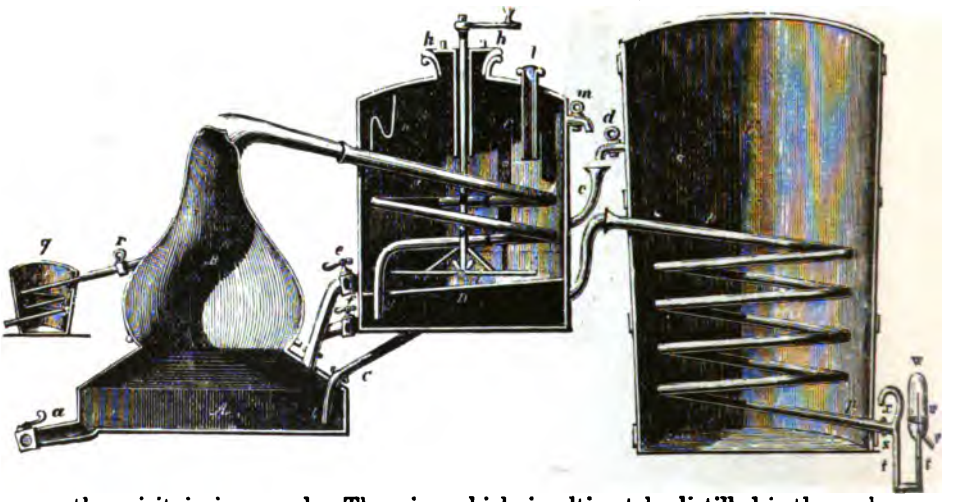
stantly agitated by the rouser *i*. The still and heater being both charged, the vapour will at first be completely condensed in passing through the worm *g*, and flowing into *D*, will close the aperture of *q* with a water- or spirit-valve. When the contents of *C* become so hot that no more condensation occurs, the vapour will be forced to escape through the liquid in *D*: this becoming heated by the constant current of vapour, will itself soon boil, and evolve vapour of greater strength than the liquid it is leaving, which is then condensed by the worm in *E*. In this manner, by one operation, spirit containing about 60 per cent. of alcohol is obtained.

An improvement upon this apparatus was made by Pistorius, who introduced a second still over the same fire. The vapours from the one still were passed directly into the wash in the other, which was thus soon brought to

the boiling point, and the vapour was condensed in a rectifier similar in principle, but somewhat modified in construction, to the one just described. Alcohol of 80 or 90 per cent. was thus obtained in a single operation. Schwarz and others have improved on the apparatus of Pistorius, but the greatest perfection in the apparatus for distillation has been attained in the arrangements of Derosne and Coffey, which have superseded all others in large distilleries. The advantages presented by these forms of apparatus are that they not only at once yield the strongest spirit, but the alcohol is more completely separated from the less volatile oils which accompany it. Derosne's apparatus, shown in Fig. 469, is extensively used in France for the preparation of brandy from wine. It consists of two stills, *A* and *B*, a distillatory column and first rectifier *C*, a heater and second rectifier *E*, a condenser *F*, a vessel *G*, which by means of the float *g* regulates the supply of wine contained in the tank *H*.

The principle of the whole method consists in bringing the wine by an uninterrupted descent into continuous contact with the vapour as it ascends. The liquid and vapour are in actual contact throughout the greater part of the apparatus. The liquid is thus deprived of spirit, while the strength of

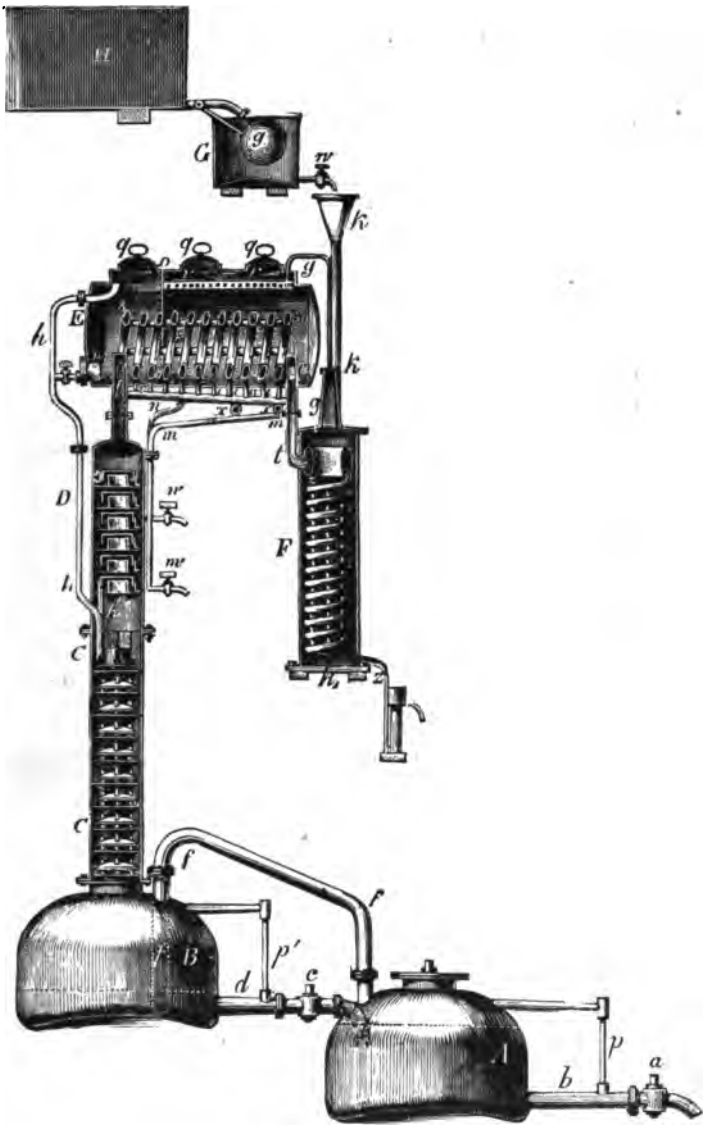
FIG. 468.



the spirit is increased. The wine which is ultimately distilled is thus substituted for the water used in the old system of condensation. The wine flows from *H* to the vessel *G*, in which it is always retained at the same level by means of the float *g*; a small stream regulated by the cock *v* flows constantly into the funnel *k*, and enters the cooler *F* at *k'*; the portion that has already been warmed by contact with the worm rises in the tube *g g* to the heater *E*, where it is discharged through a perforated gutter on to the hinder part of the coil of pipe *s s*. The wine is thus again heated in cooling the coil through which alcohol vapour is passing and condensing, and acquires almost a boiling temperature before escaping through the pipe *h h* to the rectifier *C*. In order that the wine may acquire as high a temperature as possible in *E*, a diaphragm is inserted at *o o*, which separates the vessel into two compartments communicating with each other at the lowest part only, so that the wine which flows out through the pipe *h* has previously been in contact with the hottest coils of the condenser *s s*. Arriving at *C*, it falls in cascades over a series of lenticular discs of metal which retard its descent and allow time for the rectification to be effected. The residue from the rectification called

vinasse, which collects almost exhausted in the still *B*, is run off into *A* through the pipe *d*, where it is boiled, and after losing the last portion of alcohol is discharged at *a*. During the distillation, *B* is filled only to $\frac{1}{5}$th of its depth, and *A* to $\frac{3}{4}$ths, the levels being indicated by the gauges *p* and *p'*.

Fig. 469.



Both stills are placed over one fire, so that the effect of the steam in *B* is heightened by the direct influence of the fire.

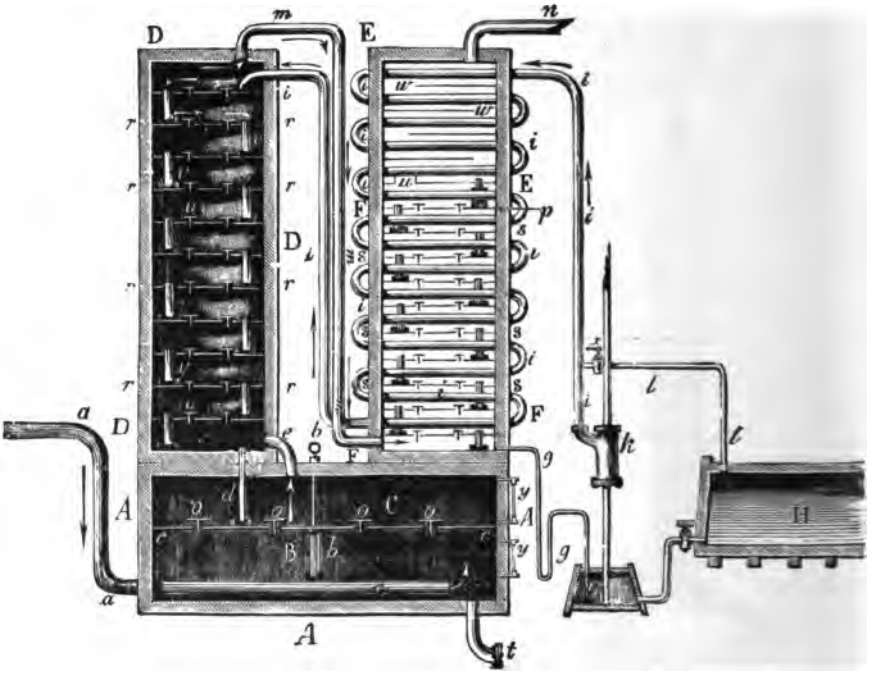
The vinasse in *A* furnishes steam for the whole process, which, with a trace of alcohol, rises in the steam-pipe *ff*, and passing through the liquid in *B*, heats it to the boiling point. The vapour rising from *B* ascends into

C, where it meets the descending rain of heated wine, from which it extracts nearly the whole of the alcohol, and is partly rectified by contact with the outside of *C*. In *D* it meets the liquid which has been condensed by the action of the wine on the coil *s s* in the vessel *E*. This is allowed to collect on several shallow stages, and through it the vapour has to force its way under the little caps shown in the drawing, before arriving at the coil *s s*. The liquid from these stages ultimately descends into the first vessel *C*. The last rectification is effected in *s s*, and the brandy then passes off to the condenser *F*, through the worm *z z*. A quantity of more or less impure spirit collects in the lower parts of the coil *s s*, which is conducted away by the short pipes *i i i* to a common pipe *v v*, whence it can be let off either into *D* to be rectified, or may be mixed with the distillate by the pipe *t*.

Coffey's still was patented in 1832. In principle, it is essentially the same as that of Derosne, but being intended to work mashed liquors, a separate boiler is employed to avoid the danger of burning.

Fig. 470 represents this form of apparatus. Coffey's still as formerly

FIG. 470.



made resembled externally a large wooden chest, being constructed of very thick planks covered on the inside with sheet-copper. Modern forms, however, are composed of two tall, thin, rectangular towers, sometimes constructed entirely of copper, but still often with wood outside, the large chest or wash collector having been abolished. It consisted of a wash collector *A A A* and two upright quadrangular columns. The one *D D D* is called the *analyser*, and is intended for rectifying the wash; the other *E E E*, the *rectifier*, answers the purpose of a heater and dephlegmator; the lower part *F F F* acting as a rectifier for the feints, whilst the upper part condenses the alcoholic vapour.

The distillation is effected on the same principle as in Derosne's apparatus, a constant current of spirituous vapour ascending in one direction

being brought into intimate contact with a stream of wash descending in the other.

The wash collector *A* is separated into two compartments, *B* and *C*, by a plate of copper *c c*. The plate *c c* is perforated with holes in the form of a sieve, and is furnished with T-shaped valves *o o o*. The analyser *D* is separated by similar plates *r r* and valves into twelve chambers; and the lower part of the rectifier *F F* contains ten chambers similarly separated from each other by the plates *s s s*. The orifices in these plates permit the vapour to pass through them, but are too small for the descent of the liquid wash, which finds its way from one chamber to the other by the short pipes *d* and *v*. When the pressure of vapour is great, the valves *o o* allow it to escape.

A constant stream of wash is drawn from *G* by the pump *k* into the pipe *i*, which supplies the entire apparatus. The supply is regulated by allowing the excess drawn up by the pump to flow back into the cistern *H* by the cock *x* through the pipe *l*. The pipe *i* enters the upper compartment of *E*, where it is separated into three branches, each of which traverses by a series of bends, only one of which is shown in the drawing, the entire height of the rectifying column *E E* and *F F*, passing from the last compartment but one by the pipe *i* to the uppermost compartment of the analyser *D D*. In the analyser, the wash flows from chamber to chamber, and arrives at length in *C* by the pipe *d*, whence it is let down at intervals into *B* by raising the valve *b*. This is done when the gauge at *y* shows that the chamber *c* is quite filled with liquid. It is essential that a stratum of liquid about an inch in depth should be allowed to rest on the plates *r r*, and the short pipes *v* are consequently allowed to project about that much above the level of the plate, while their lower extremities dip into shallow cups which remain filled with liquid and prevent the escape of vapour through them.

In *B*, the nearly exhausted wash meets the current of vapour issuing from a boiler through *a a*, and the last trace of spirit is separated from it and carried with the vapour through the sieve apertures of the plate *c c*; it thus passes through the entire mass of liquid in *C*, which it nearly exhausts of alcohol, and arrives through *e* in the lowest compartment of the analyser; here it ascends through the wash collected in each compartment, becoming cooler in its progress, acquiring alcohol and losing water, until it is transmitted by the pipe *m m* to the lowest chamber of the rectifier. In *F*, it traverses the plates *s s* in a similar manner, passing through the feints which have collected upon them in inch-thick layers by the rectification in *E*. These feints are returned by the pipe *g g* to the cistern *G*, and pumped up again with the fresh wash. The vapour arriving in *E* by the wide aperture *u* is compelled by the plates *w w*, which are not perforated, to follow the windings of the pipe *i* in its entire length, by which means it is condensed, and the wash flowing through the pipes is heated. The condensed vapour collects on the bottom of *E*, and is conveyed by pipes at *p*, not shown in the drawing, to another condenser.

A plan similar to this has been adopted by Hill for distilling gas-liquor, and will be described elsewhere.

The modern form of Coffey's still, and the general arrangement of plant used in connection with it are shown in Figs. 471, 472, 473, which are from plans supplied by Messrs. Blair, Campbell, and McLean, of Scotland Street Copper Works, Glasgow. Fig. 471 shows the analyser and rectifier columns in elevation and in vertical section; Fig. 472 shows the general arrangement of boilers, pipes, receivers, pumps, and other plant, in elevation; and Fig. 473 is a ground plan of the whole arrangement, showing the position of all parts of the apparatus. The following reference letters apply to all the illustrations:—

A is the analyser column; B, the boilers; C, the cast-iron condensing tank; D, the copper wash-pipes; E, the steam stop-valve; F, the copper dip-pipes; G, the copper pans; H, the copper vapour-pipe; I, the position of pumps and

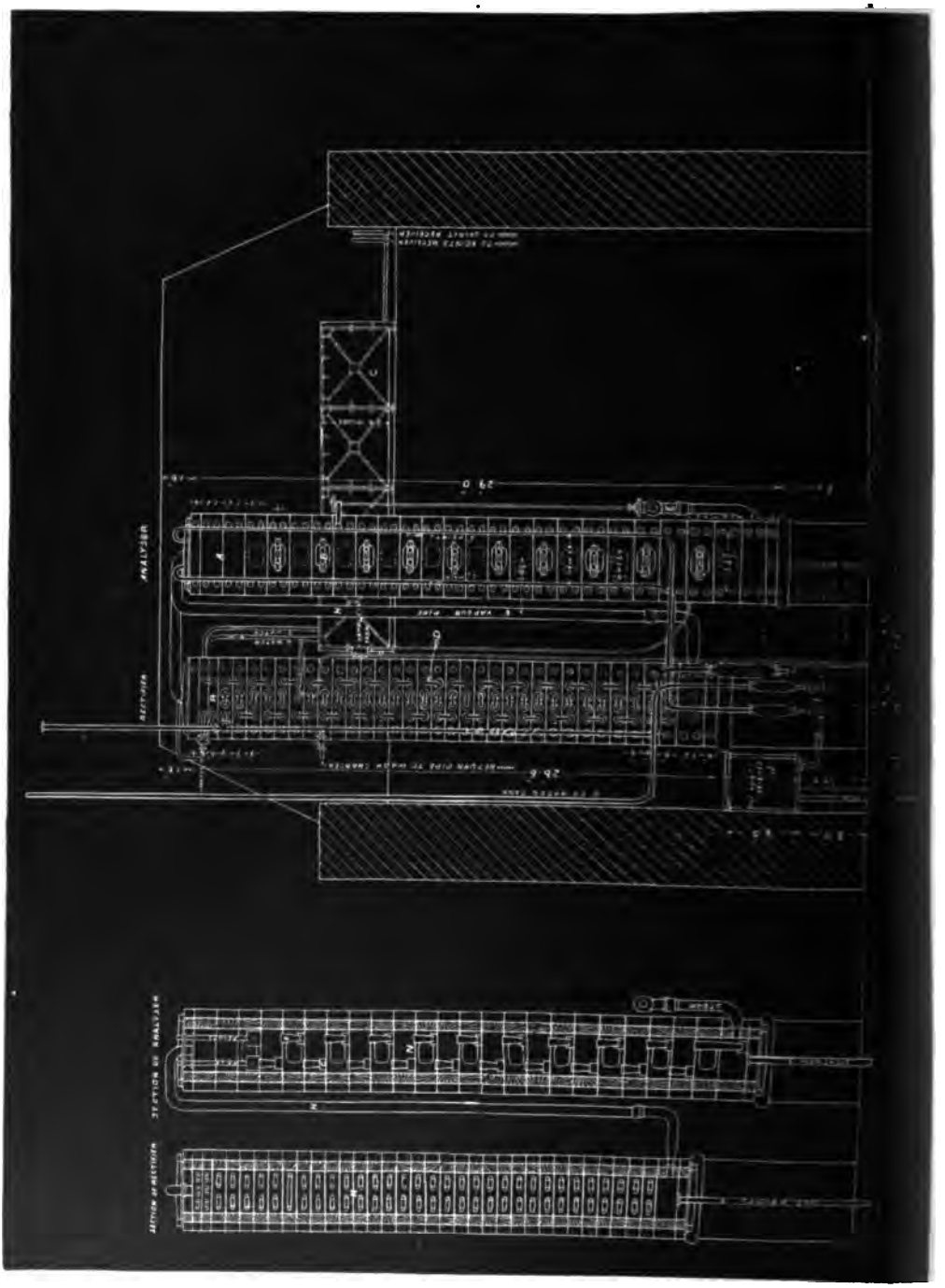


FIG. 471.

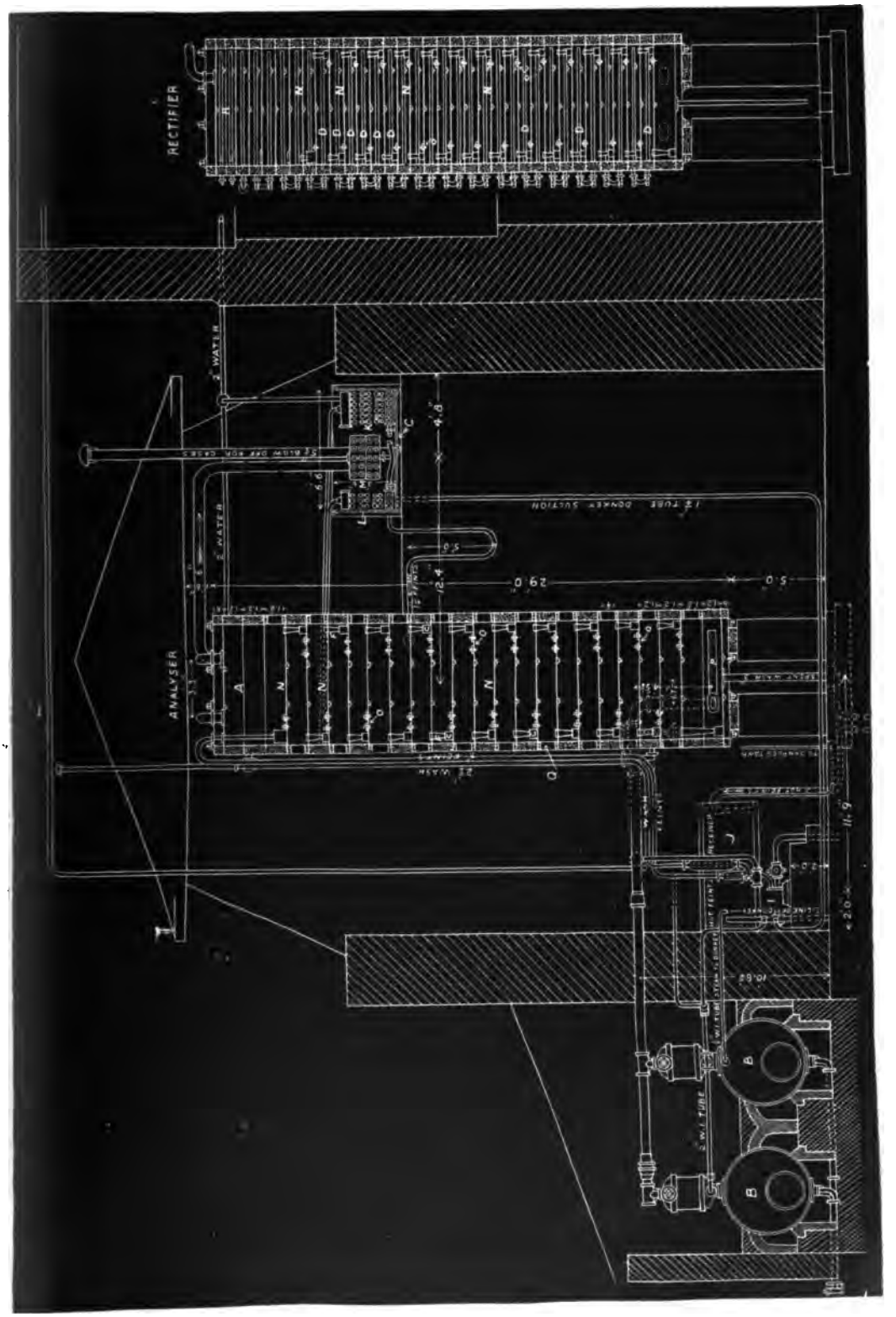

RECTIFIER
ANALYSER
2" WATER
2" WATER
12" TUBE DONKEY SUCTION
29.0
0.5
0.5
4.8
2.4
6.6
11.9
20.4
10.69
2" WATER
2" WATER
2" WATER
2" WATER
B
B

FIG. 472.

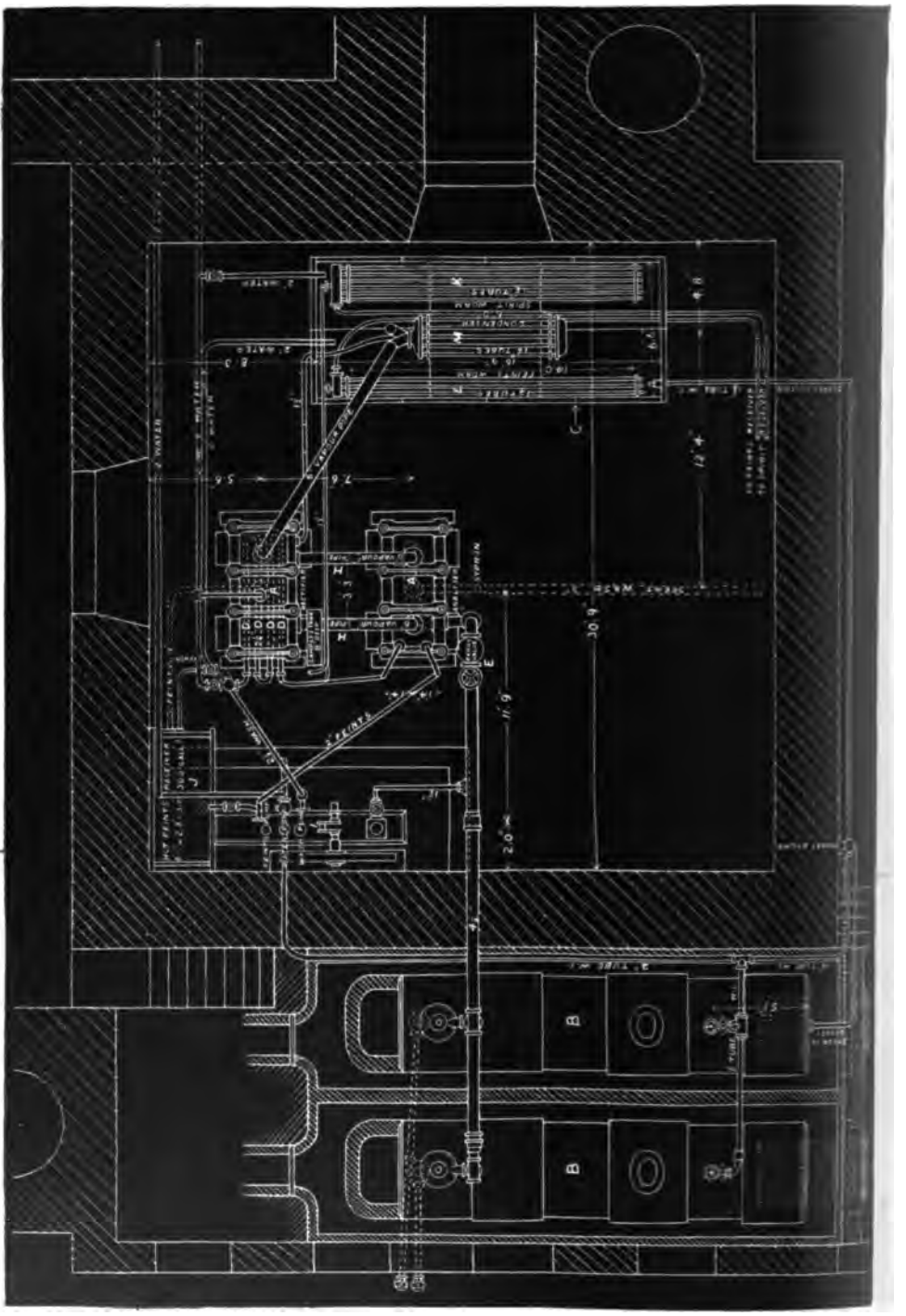


FIG. 473.

engine; J, the hot feints receiver; K, the copper spirit-worm; L, the copper feints-worm; M, the copper condensing-worm: N, the copper division-plates; O, the brass valves; P, the copper perforated steam-pipe; Q, the manhole doors; R, the rectifier column.

The method of working this modern plant is as follows:—

When commencing an operation, the wash-pump is set in motion, to charge all the zigzag pipes, until the wash passes over into the analysers. The pump is then stopped, and the steam let into the bottom of the apparatus.

The steam passes up through the chambers and by the pipe into the analysers, whence it descends through to the bottom of the rectifier. It then rises through the chambers enveloping the zigzag pipes, and rapidly heats the wash contained in them. When the attendant perceives, by feeling the bends, that the wash has been heated in several layers of these pipes—perhaps eight or ten layers, but the number is not of much moment—he again sets the pump to work, and the wash, now boiling hot, or nearly so, and always in rapid motion, flows from the pipe, and passes down from chamber to chamber through the dropping pipes. No portion of the wash passes through the small holes perforated in the diaphragms which separate the chambers. These holes are regulated both in number and size, so as not to be more than sufficient to afford a passage for the vapour upwards, under some pressure. The holes, consequently, afford no outlet for the liquor, which can only find its way down in the zigzag course. It is obvious, therefore, that the wash, as it passes down, is spread into strata as many times as there are diaphragms, and is thus thoroughly exposed to the action of the steam constantly blowing up through it. As it falls from chamber to chamber, the alcohol in it is volatilized by the steam passing upwards; and, by the time the wash has reached the large chamber, no trace of spirit remains in it. The wash, as it descends from the analyser, accumulates in the large chamber until it becomes nearly filled, when the attendant opens the valve and discharges the contents into the lower compartment; then, shutting the valve, the wash from the analyser again accumulates; and when it is nearly full, the contents of the lower chamber are discharged from the apparatus altogether, through the cock, and when it is empty the charge is let down from the upper chamber by opening the valve as before; thus the process goes on, so long as there is any wash to supply the pump.

When the wash is gone, a quantity of water is let into the reservoir and pumped through the pipes, to finish the process and obtain the last portions of alcohol. This winding up of the operation, by sending water through the pipes, takes place on the distillation of every "back" of wash, in consequence of the Excise regulation, which requires the distiller to keep the produce of each "back" separate from that of any other. Were it not for this regulation, the distillation would go on uninterruptedly so long as there was any wash in stock; the addition of water for winding up would be necessary but once during the distilling period, and the manufacturer would save much time and fuel at present wasted by these interruptions.

It has been already said that, in the ordinary course of the operation, the wash is stripped of all its alcohol by the time it has reached the bottom of the analyser; but, as a precautionary measure, chambers have been added, in each of which the spent wash is exposed for about half-an-hour to the action of the steam blowing through it. There is a small apparatus, by which a portion of the steam from the chamber is condensed, cooled, and made to flow constantly through a sample jar in which is an hydrometer, or, what is better, two glass bulbs, one of the sp. gr. 1.00, and the other 0.998. When the lighter of these bulbs floats in the sample, it is all right, and the chamber may be emptied without any risk of loss.

The course of the wash being understood, that of the steam will require very little description. The steam, as it rises, is first blown through the charges of spent wash in the lower chamber; thence it passes up through the layers of wash on the eleven diaphragms of the analyser. In its course, it abstracts from these layers of wash their alcohol, depositing in its place an equivalent of water. After traversing the whole of the analyser, the vapour, now containing much alcohol, passes by the pipe into the bottom of the rectifier, and, as it ascends, it envelops the pipes heating the wash, and simultaneously parting with its more watery portion, which is condensed, and falls in a state of ebullition on the several diaphragms of the rectifier. By the time the vapour reaches the passage in the bottom of the finished spirit condenser, it is nearly pure alcohol; and as it is condensed by the wash in the pipes, and falls on the diaphragm, it is conveyed away by the pipe to a refrigerator. At the top of the spirit condenser is a large pipe, which serves as a vent for the incondensable gas which is disengaged in the process, and this pipe also communicates with the refrigerator; so that, should vapour at any time pass out of the apparatus, no loss is sustained beyond the waste of fuel caused by condensing that vapour by the water of the refrigerator, instead of by the wash of the condenser.

The liquor formed on the several diaphragms of the rectifier, after the vapour, passing up from plate to plate, has blown through it, descends to the bottom in the same manner as the wash falls from chamber to chamber in the analyser; but this condensed liquor still contains a portion of alcohol, and it is conveyed by the pipe to the pump by which it is raised up with the wash to be again distilled.

A thermometer shows the temperature of the wash as it issues from the pipe into the analyser, which is the only guide required for managing the operation, for, when the temperature is what it should be, nothing can go wrong in the work. Whenever the thermometer indicates too high a temperature, more wash should be let into the apparatus, and *vice versâ*—the quantity being regulated by the tap and the pipe. It would seem, however, that very little nicety is requisite on this point. Experience has proved that the fluctuation of a few degrees above or below the proper heat is of little consequence, and that it is very seldom found necessary to alter the supply of wash.

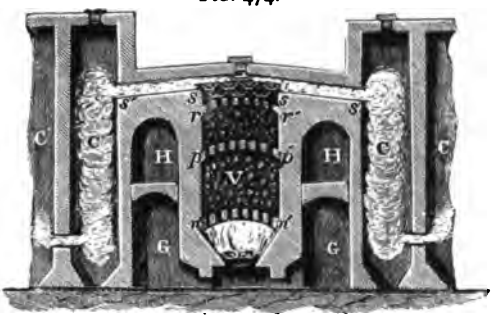
The water for supplying the boiler passes through a long coil of pipe immersed in boiling spent wash, by which means it is raised to a high temperature before it reaches the boiler. It will be seen that the vapour passing through this apparatus is also condensed by the wash, not by water, and therefore no heat is wasted, as in the ordinary process of distillation. The consequence of this is that about three-fourths of the fuel used with the common stills is saved, a matter of very great importance.

According to the ordinary process, it requires twelve pounds of coal to distil a gallon of proof spirits; but when coals of a superior quality are employed, and the stills are properly constructed, less will suffice. Of the twelve pounds referred to, nine pounds are saved by the new system; and, assuming the whole quantity of spirits distilled in the empire to be 36,000,000 gallons (which, with the Colonies included, is not over the mark), the saving of fuel arising from the new methods of distilling, if universally adopted, will amount to 140,000 tons of coal per annum.

One of Mr. Coffey's stills at Inverkeithing works off two thousand gallons of wash per hour, and one, which the inventor subsequently erected at Leith for the same proprietors, upwards of three thousand gallons. There are several of equal magnitude, and it is stated that those now at work, or being erected, are capable of distilling half a million gallons of wash per day, this wash yielding, on an average, from 11 to 12 per cent. of proof spirit.

Several of the metals which are volatile at a high temperature are separated from their ores and purified by distillation. Fig. 474 shows the distillatory furnace employed at Idria for obtaining mercury from the sulphide. The ore is placed in large pieces upon the perforated arch $n n'$ immediately above the furnace; the arch $p p'$ is covered with smaller pieces, and above $r r'$ the powdered mineral and the residues from former operations are placed in small earthenware dishes. A powerful fire is made under the lowest arch, the flame and products from which pass through the several layers of mineral, while currents of air from the channels H, G, penetrate the walls of the kiln and oxidize the sulphur which is in combination with the mercury. The metal thus liberated passes over in the form of vapour by the flues $s s'$ and is condensed in a series of chambers $C C C$.

Fig. 474.



Destructive Distillation.—The distillation of substances which are decomposed in the process, is carried on to a great extent for the sake of the products. Sometimes the residue which is left after the removal of the volatile products is the aim of the operation. This is the case with all the processes of charring which have been described in the previous pages, and where in many instances the volatile products are not collected. When the volatile products have sufficient commercial value to repay the cost of condensing apparatus, the operation of charring is conducted in close vessels, and becomes a process of dry or destructive distillation. The nature of the substance, the mode of conducting the operation, and the character of the products vary so much in these processes, that no general rules can be laid down for the construction of apparatus, which must therefore be looked for in other divisions of this work, where the several branches of manufacture involving dry distillation are described.

Fig. 475.

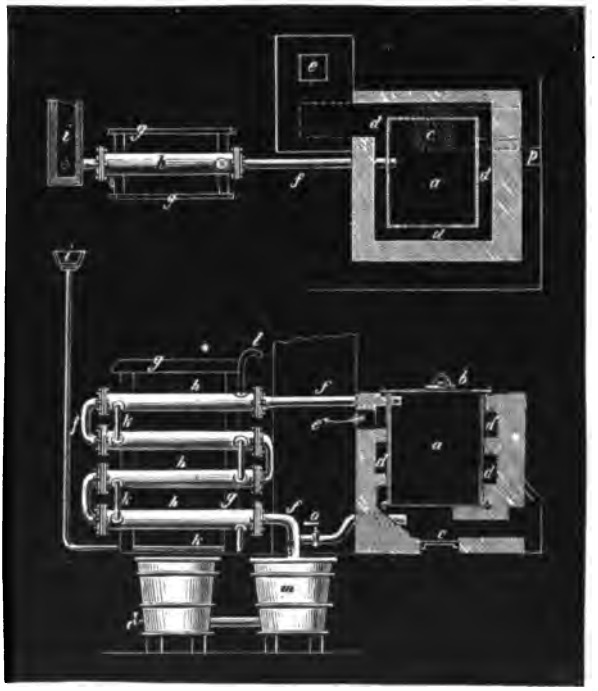
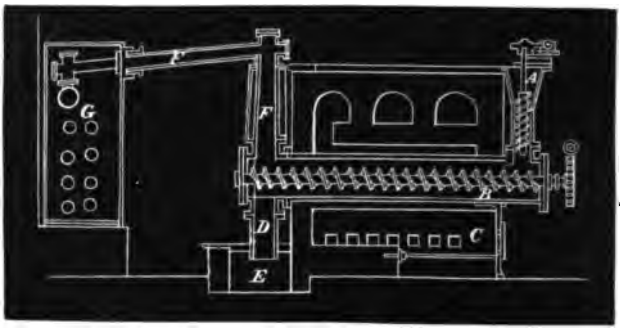


Fig. 475 (p. 607) represents a system adopted for distilling wood for the production of tar, pyroxylic spirit, and wood-vinegar. *a* is a strong wrought-iron box with an air-tight lid *b* set over a fire at *c*, the flames from which circulate round the sides of the box in the flues *d d d*, escaping at *e* to the chimney. The products of distillation pass off by the pipe *f*, which is surrounded by a wider pipe *h h* in several of its bends, through which a current of cold water is flowing in the opposite direction to the volatile products in the inner pipe. Cold water is supplied at *i*, and passing from one pipe to

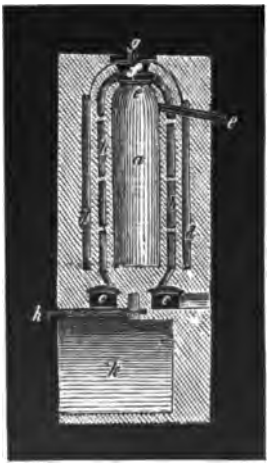
Fig. 476.



the other by the connecting pieces *k*, passes off at *l*. The gaseous products of distillation, which are valueless as illuminating agents, are conducted to the fire by the cock *o*, where they develop considerable heat in burning, whilst the condensed products are collected for purification in the vessels *m*. In this arrangement, the process must be interrupted with every fresh charge of material in the box *a*.

Fig. 476 represents the close retorts invented by Halliday for the distillation of refuse sawdust, tan, dye-woods, and other ligneous matters which are necessarily in the state of coarse fragments or powder. The process of distillation is continuous, a constant supply of material being introduced by means of a screw into the front part of the retorts, and the residuary charcoal discharged in a similar manner. The retorts are in the form of cast-iron cylinders arranged over furnaces in a manner similar to that adopted in gas works, the screws by which the material is made to travel from the front to the back of the retort being of nearly the same diameter as the retort itself. Each retort is furnished with a wide pipe at the back, the lower extremity of which dips below the surface of water contained in a tank into which the charcoal falls, whilst another pipe carries away the volatile products to a condenser.

Fig. 477.

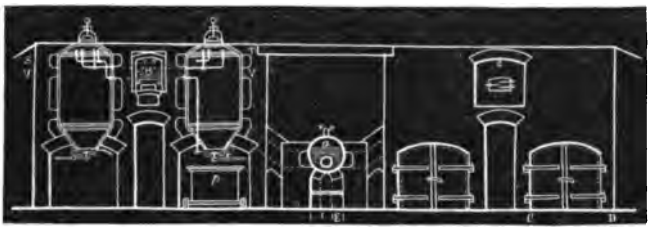


An oven for charring peat and collecting the volatile products (Fig. 477) was erected at Courcy-sur-Ourcq, near Meaux. It consisted of a cylindrical retort *a*, heated by the flues *b*; and in order to maintain the temperature as uniform as possible, there were open spaces *d* left in the wall, filled with air. The flames ascended from the fire-places *c*, and the smoke passed off through an opening in the metal plate *g* on the top. The peat was thrown in at *e*, and when full the retort was closed by a strong cast-iron plate *f*, which was covered with sand and ashes,

over which the smoke from the fire passed. The gaseous products escaped by a pipe *l* to the condenser, and when the operation was finished the charcoal was drawn out into a pit *k* through the bottom of the retort, which consisted of an iron damper *h*, movable from the outside.

Heated steam has been proposed as the source of heat in certain pro-

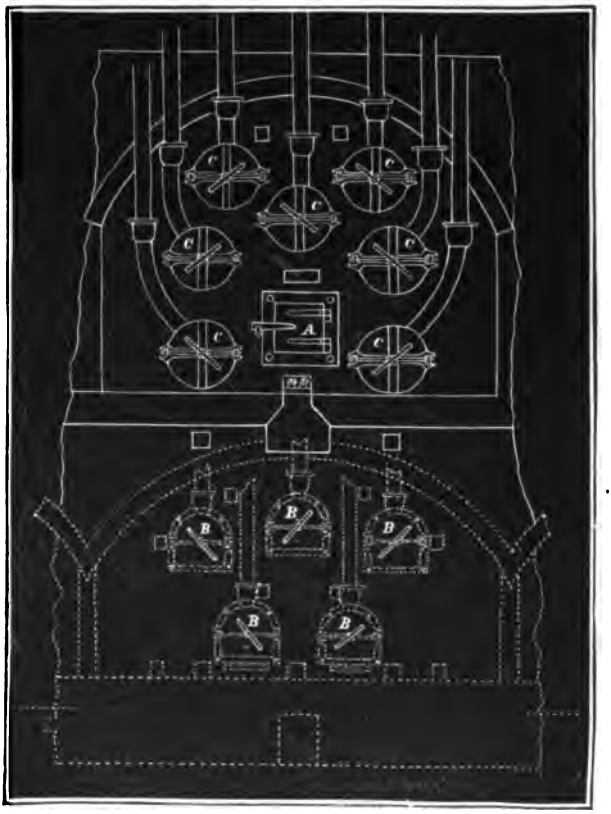
FIG. 478.



cesses of destructive distillation. Thus, for distilling turf or peat, the apparatus sketched in Fig. 478 was patented by Vignoles.

The steam generated in the boiler *a* is heated to a high temperature by passing through a series of pipes *H*, which are placed in a separate furnace, and is conveyed to a number of cylindrical vessels containing the peat, which are also heated by the waste heat from the boiler furnace. The volatile products from the peat are carried away by the steam and condensed in suitable apparatus, whilst the charcoal is discharged from the bottom of the cylinders into trucks placed below them.

FIG. 479.

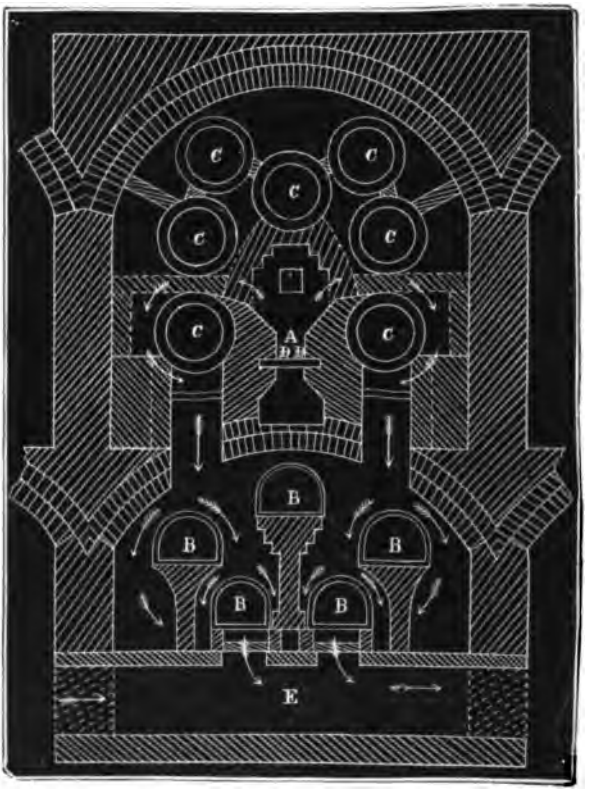


Heating Gas Retorts. — An economical arrangement for distilling coal for the manufacture of gas is shown in Figs. 479 and 480.

C C C represent seven cylindrical clay retorts arranged round the common furnace *A*. These receive the direct heat from the fire; the hot gases, passing by flues in a downward direction, as indicated by the arrows,

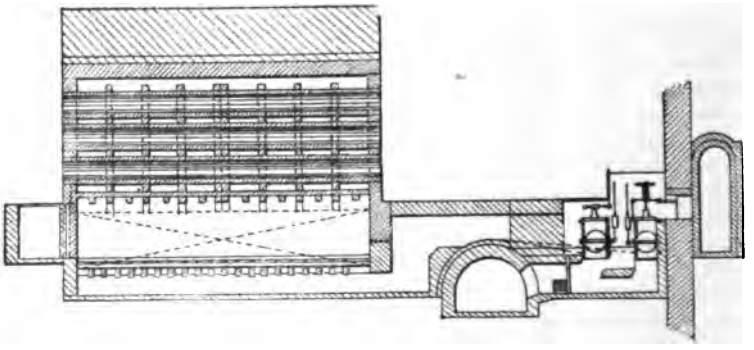
Fig. 480, subsequently heat five cast-iron retorts *B B B* situated below the furnace, before escaping to the chimney by the flue *E*. The volatile products of the distillation escape by the pipes shown in Fig. 497 from the necks of the retorts to a main where the tar, and other condensable products, are partially collected; and they are subsequently passed through extensive condensers to separate the liquid products completely from the gases.

Fig. 480.



It is not surprising that the heating of the retorts in gas works should have been recognized at an early date as an important field for the application of gas firing. Mr. Charles Hunt,* in a paper on this subject in February 1884, said that "heating gas retorts by fuel in the gaseous form, as a substitute for its common application in the solid state, dates almost as far back as the introduction of the regenerative system by the late Sir William Siemens, more than twenty years ago. The success that attended the latter in its application to other industries led to its being applied experimentally in at least two gas works in this

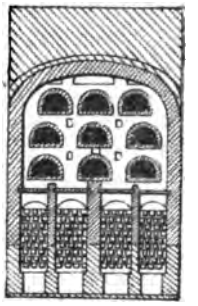
Fig. 481.



* "Jour. Soc. Chem. Ind.," vol. iii. 1884, p. 89.

country—namely, the Brick Lane Station of the then Chartered Gas Company, and the Windsor Street Works, at that time belonging to the late Birmingham Gaslight and Coke Company. In neither case, however, were the results such as to secure for it a more extended use, although almost simultaneously it obtained a firm and (as it proved) enduring footing at the works of the Paris Gas Company, where, with sundry modifications of detail, it has ever since been very largely employed. Figs. 481 and 482 show substantially the arrangement which, down to the year 1875 (when it was finally abandoned), was used in Birmingham for heating six beds of retorts. It is that of the familiar alternating system, with regenerators for both gas and air, worked by means of reversing valves, the producers (not shown in the figure) being of the ordinary kind with sloping grates, placed at a convenient distance outside the retort house, to which the gas was conveyed by the usual wrought-iron condensing tubes." These figures also give the main features of the plan originally introduced into the Paris Gas Works, but not the modifications which were subsequently introduced.

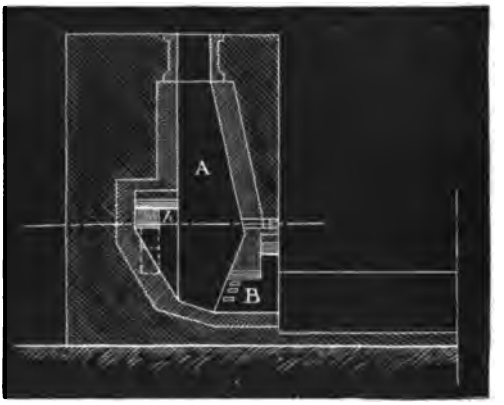
Fig. 482.



In the opinion of Mr. C. Hunt this system was unsuccessful in Britain on account of its greater complexity, uncertainty of action, and first cost, as compared with the simple and convenient, although more wasteful, method of direct firing with solid fuel.

In view of the progress which has been made in this matter since these early days, it appears that success has mainly depended upon having continuous regeneration of heat and an arrangement of retort benches with the gas producers in immediate proximity to the charging doors, so that a large portion of the initial heat of the coke should be transferred to the producers by charging them with the hot coke from the retorts.

Fig. 483.

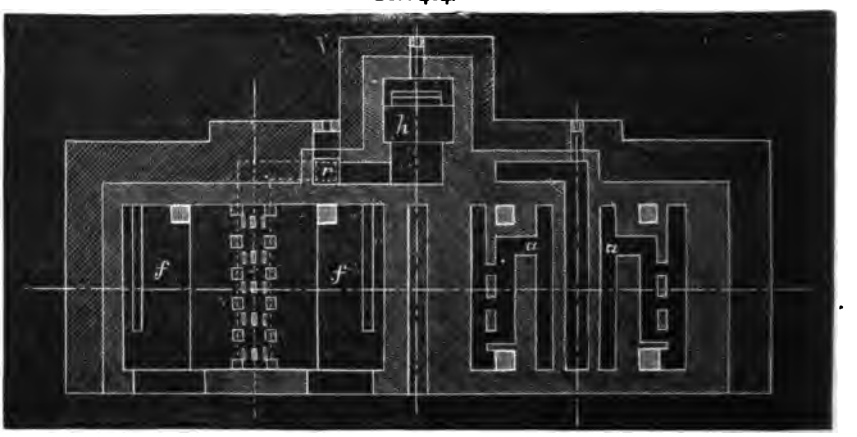


An early form of retort heating gas furnace—perhaps the earliest form introduced—having this arrangement, was that of MM. Oichelhäuser, Müller, and Eichelbrenner, employed in the gas works at Montreuil.* It is illustrated by Figs. 483–486, as applied to heating a pair of groups of seven retorts each placed side by side, the gas producer being at the back of the retort bench in the centre. This producer or "shaft" is shown in section at A on Fig. 483, and on plan in Fig. 484. B is a step grate for admission of air, and to prevent the coke falling out; the carbonic oxide formed in the producer being led away by the opening *h* (in Figs. 483 and 484) from which it passed by *r* (Fig. 484) to S (Fig. 485), a channel placed in the axis of the retort setting at the bottom. From the top surface of S, a series of openings led the gas into the furnace, where it met the air for combustion

* See "Gas Engineers' Diary, &c.," 1882, p. 93, *Etudes sur la Combustion*, by M. Fichet, *Mém. de la Soc. des Ingén. civils*, 1874, p. 670; "Fuel, its Combustion and Economy," Williams and Clark, p. 242.

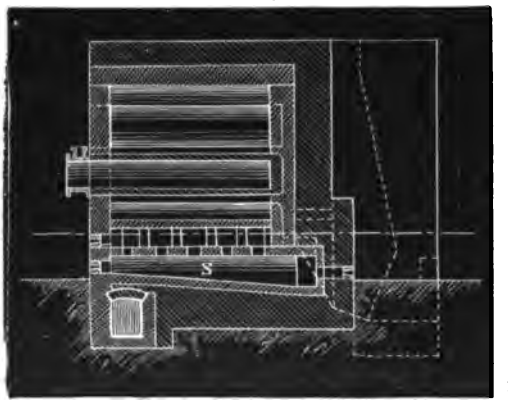
from two passages *a* (Fig. 484) placed alongside S, the air having previously been heated by traversing passages in the setting which were heated by conduction. This arrangement has been very successful, having in one form used, as fuel for the distilling operation, 17½ per cent. in the shape of

FIG. 484.



coke of the weight of coal distilled, a single furnace with ordinary grate holding the same number of retorts having previously consumed coke amounting to from 30 to 35 per cent. of the weight of the coal distilled. In the latest form it is said that one generator serves for two benches of eight retorts each, and is charged every six hours, the average production of gas in twenty-four hours from eight retorts being 65,000 cubic feet, and the consumption of fuel for every hundredweight of coal carbonized being 16 lbs.

FIG. 485.

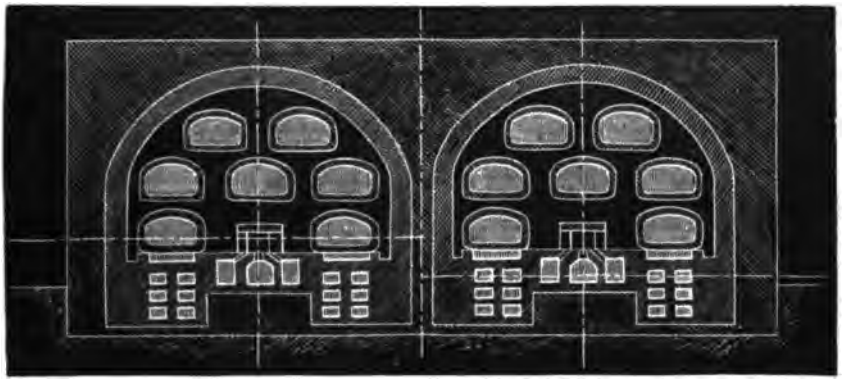


Mr. G. E. Stevenson has remarked* that the first generators applied to gas retorts in Germany were those of Didier, Hasse, and Liegel. "In the two first" of these, he says, "success was not obtained because the destruction of the lining of the generators was too great. The furnaces had large horizontal openings at the bottom on the level of the hearth, and the fire-clay lumps surrounding these openings were quickly destroyed." Liegel claimed to treat successfully the clinker, on the system of melting it and running it out at the bottom of the furnace, "by so constructing his furnace that the partially melted clinker remained as a thin stratum, covering and protecting the brickwork, and the superfluous clinker escaped from a narrow slot at the bottom of the furnace, falling directly down into an ash-pit, and not like the Didier, remaining on a hearth in proximity to the furnace sides until drawn out by rakes." The system of dealing with the residue on the plan of preventing the formation

* "Min. Proc. Inst. C.E.," vol. lxxxiv. p. 98.

of clinker, and reducing the residue to a soft ash to facilitate its removal, was originated by Dr. Schilling, assisted by Dr. Bunte, at the Munich Gas Works. These inventors placed a flat pan or tank containing water beneath the grate of the generator, and evaporated the water by conducting the waste gases under the pan after they had left the regenerator. In one arrangement of Dr. Schilling's system, a steam-pipe is shown which is led under the grate of the generator. In Klönne's arrangement also, water is

FIG. 486.



used under the generator grate, and the Siemens generator at Glasgow has been modified to the extent of having external jets of steam directed upon the incandescent coke at the openings for air at the level of the hearth.* In the Wilson producer, as arranged for this purpose, steam and air are delivered together in the interior of the producer at the centre of the hearth.

The main object, according to Mr. Stevenson, in the application of gaseous firing to retorts is the adaptation of a suitable system of regeneration which combines efficiency with economy in the construction, and does not occupy an unnecessary amount of space. For the latter reason, the

FIG. 487.

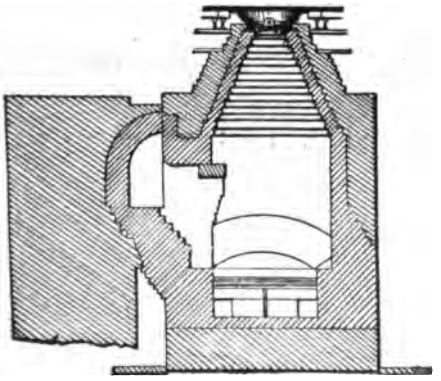
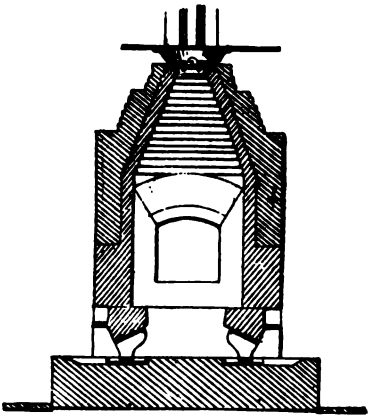


FIG. 488.

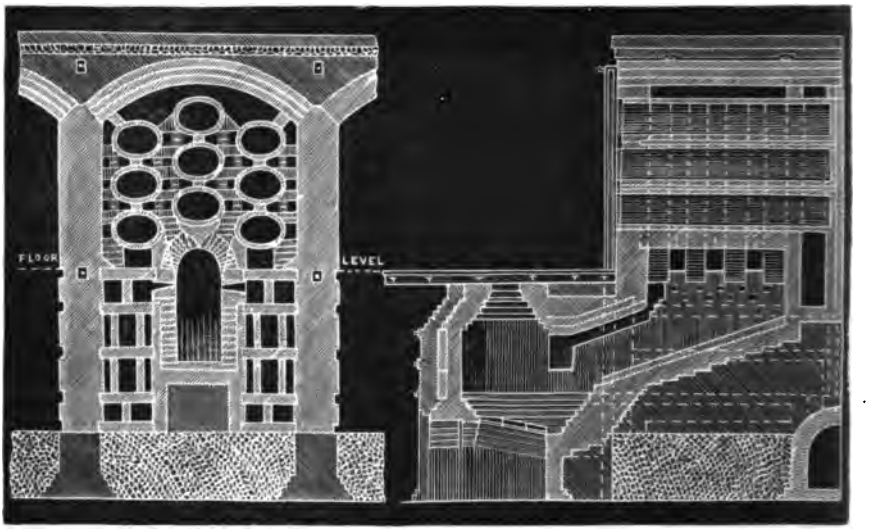


regenerating flues in all the systems hitherto adopted have been placed below the retort setting on either side of the furnace. There is no reason, however, why, in small gas works especially, a serviceable plant should not be obtained for a small outlay on the plan of having iron-pipe regenerators

* See "N.E. Assoc. of Gas Managers" 1882.

placed above the retort setting, as was proposed by Mr. Wilson to the N.B. Assoc. of Gas Managers (1881).

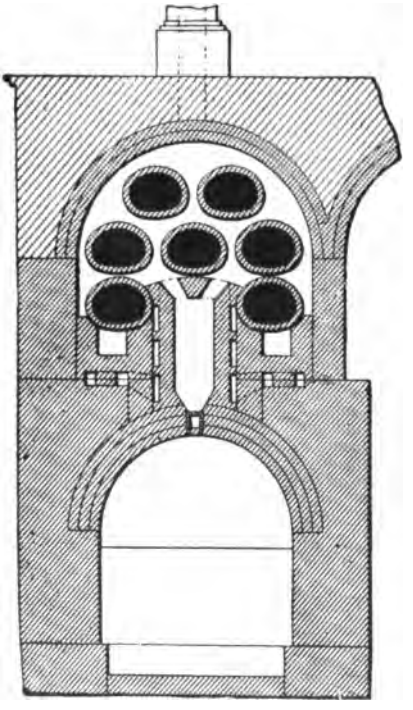
Fig. 489. Fig. 490.

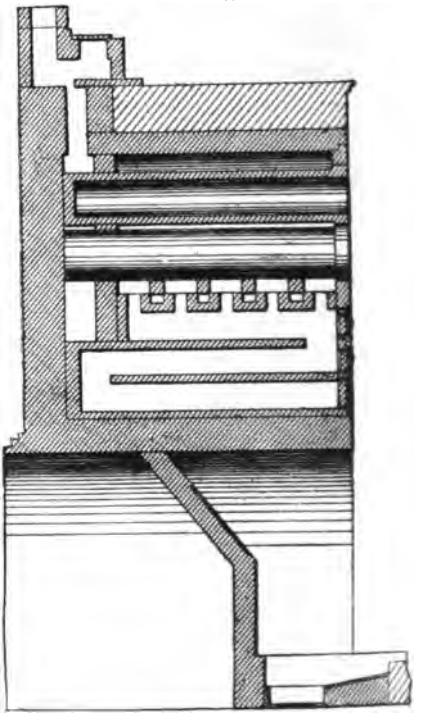


The Dessau or Didier generator, as used at Dresden, is shown in Figs. 487, 488.

Liegel's arrangement is illustrated by Figs. 489, 490, these figures

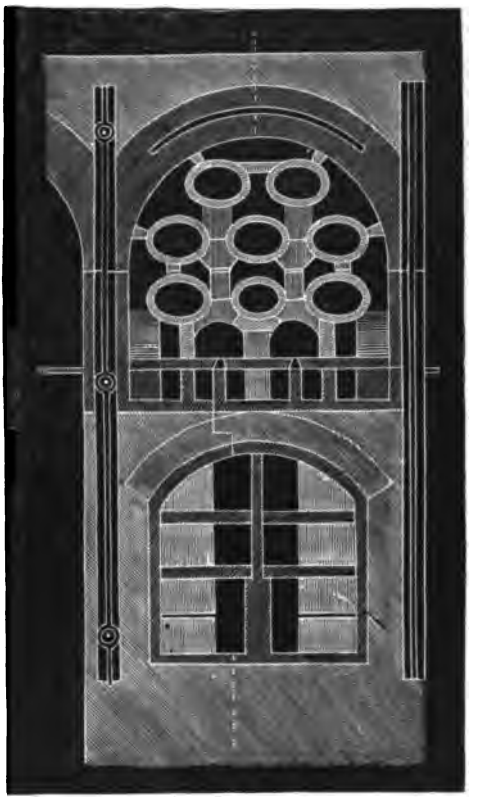
Fig. 491. Fig. 492.





having the modifications of the original Liegel arrangement which were proposed by Mr. G. E. Stevenson. In Liegel's plan, shown in the Gas Engineers' Diary and Text Book for 1882 (p. 97), the generator is placed almost entirely under the retorts with a view to utilize the heat radiated from this portion of the apparatus. Liegel's plan is understood to have been the first constructed with what is called a "slit" generator — *i.e.*, "a generator terminating in a long narrow slit for the admission of the primary air-supply" — and is also said by Mr. C. Hunt* to have been "the prototype of the first generator furnace constructed in England at the Old Kent Road Gas Works by the then engineer, Mr. G. Livesey.† This latter arrangement is said to have been improved by Mr. W. A. Valon, of Ramsgate,‡ whose plan is illustrated by Figs. 491, 492. Mr. Valon aimed at simplicity in construction and lessened first cost, but apparently at the expense of the size of the regenerator flues, although he maintained that he obtained results which were as good as those obtained with more costly arrangements.

Fig 493



As regards the extent of regenerating surface provided by the various systems, Mr. Stevenson remarks that "the systems of Schilling and Klönne possess the most complete regeneration, and give the most economical results as regards the consumption of fuel, while that of Liegel is less expensive, and gives a high heating power, but uses a somewhat greater proportion of fuel."

Dr. Schilling's system is shown in Figs. 493 and 494, this being its form as improved by the inventor and Dr. Bunte, and described in the *Journal für Gasbeleuchtung*, where it is said of it that it consumes only 14 lbs. of fuel per 100 lbs. of coal carbonized.

Klönne's arrangement, which has been erected at Birmingham Gas Works and in Scotland, has found favour in this country on account of "its superior adaptability," according to the opinion of Mr. C. Hunt. Figs. 495, 496, illustrate the arrangement as devised by Herr Klönne, and Figs. 497, 498, show the system as modified by Mr. Hunt, and erected by him at the Windsor Street Gas Works in Birmingham.

The Siemens plan, as finally adopted at the Glasgow§ Gas Works, is

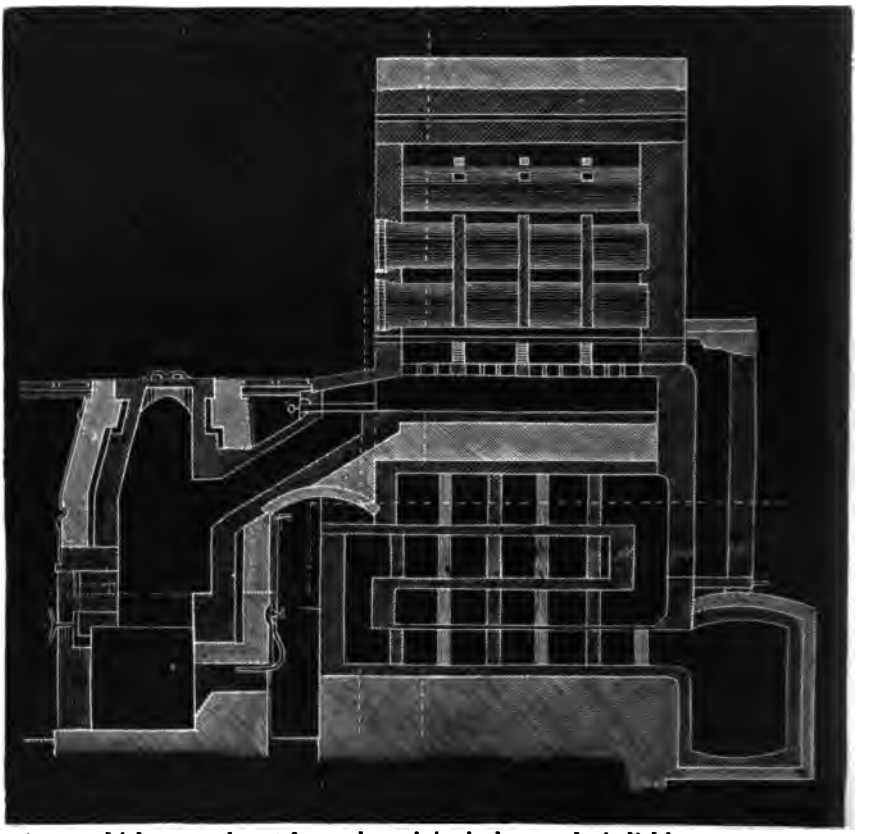
* "Jour. Soc. Chem. Ind.," 1884, p. 92.

† See Mr. F. Livesey, Brit. Assoc. Gas Managers, London Meeting, 1880, "Jour. of Gas Lighting," 1880. ‡ See "Jour. of Gas Lighting," vol. xli. pp. 269–270.

§ See "Jour. of Gas Lighting," vol. xli. p. 1139; "Jour. Soc. Chem. Ind.," 1884, pp. 92–94; "Engineering," Jan. 19, 1883; "Proc. N.B. Assoc. Gas Managers," Feb. 1884.

shown in Figs. 499, 500, this plan having been arrived at by increasing the height of the generator relatively to its diameter, introducing jets of

FIG. 494.



steam, which were absent from the original plan, and abolishing regenerator flues constructed of iron or steel plates in favour of fire-brick passages.

FIG. 495.

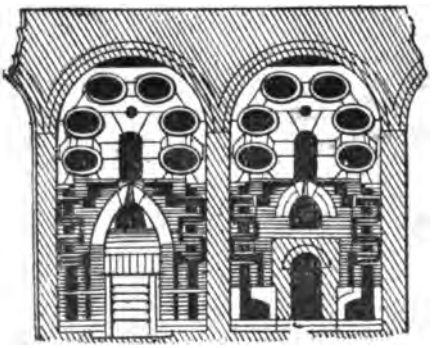
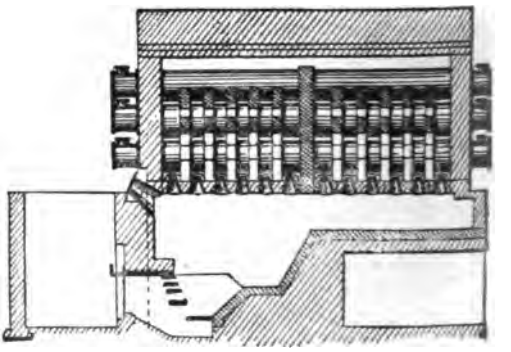


FIG. 496.



Finally, Figs. 501, 502 (pp. 618 and 619), show the plan with iron-pipe regenerators proposed by Mr. Alfred Wilson,* who remarked, "as regards the

* "Proc. N.B. Assoc. of Gas Managers," July 1881; "Jour. of Gas Lighting," 1881.

durability of a cast-iron pipe regenerator," that the "experience gained with the hot-blast stoves of iron-smelting furnaces over many years has proved, first, that of all forms of wrought or cast iron the most durable is a cast-iron pipe, either cylindrical or oval, and of moderate dimensions as regards cross-

Fig. 497.

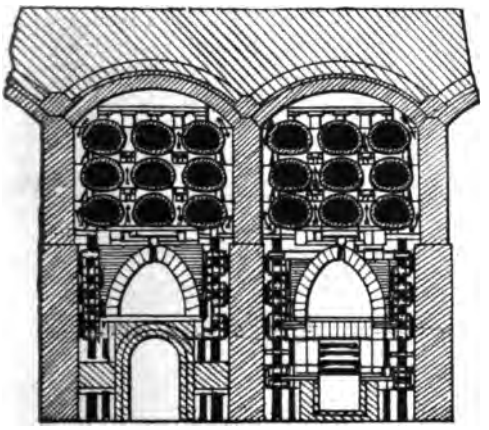
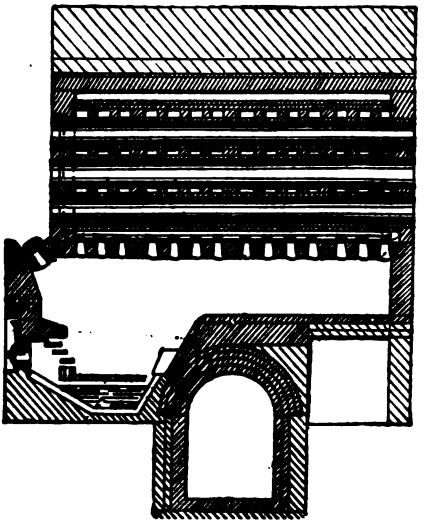


Fig. 498.



sectional area; secondly, that heating stoves composed of cast-iron pipes will stand from five to ten years subjected to a temperature which heats the air passing through them to 1000° F."

Distillation is sometimes carried on in a vacuum, when apparatus

Fig. 499.

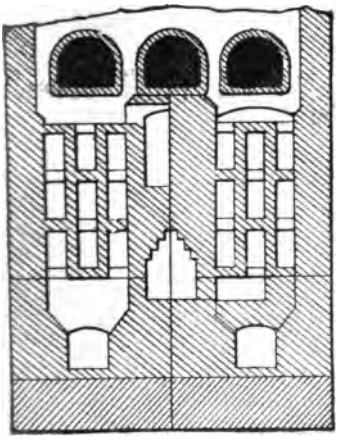
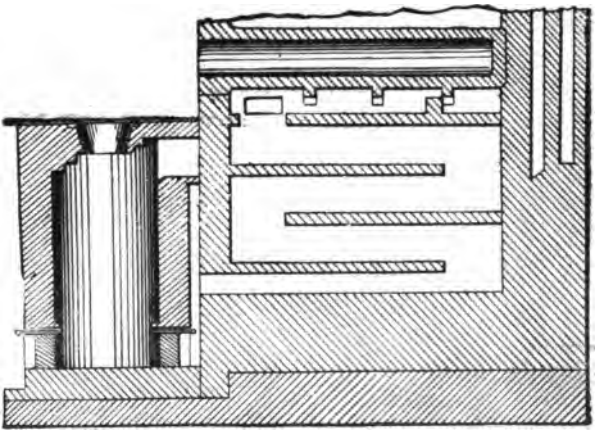


Fig. 500.



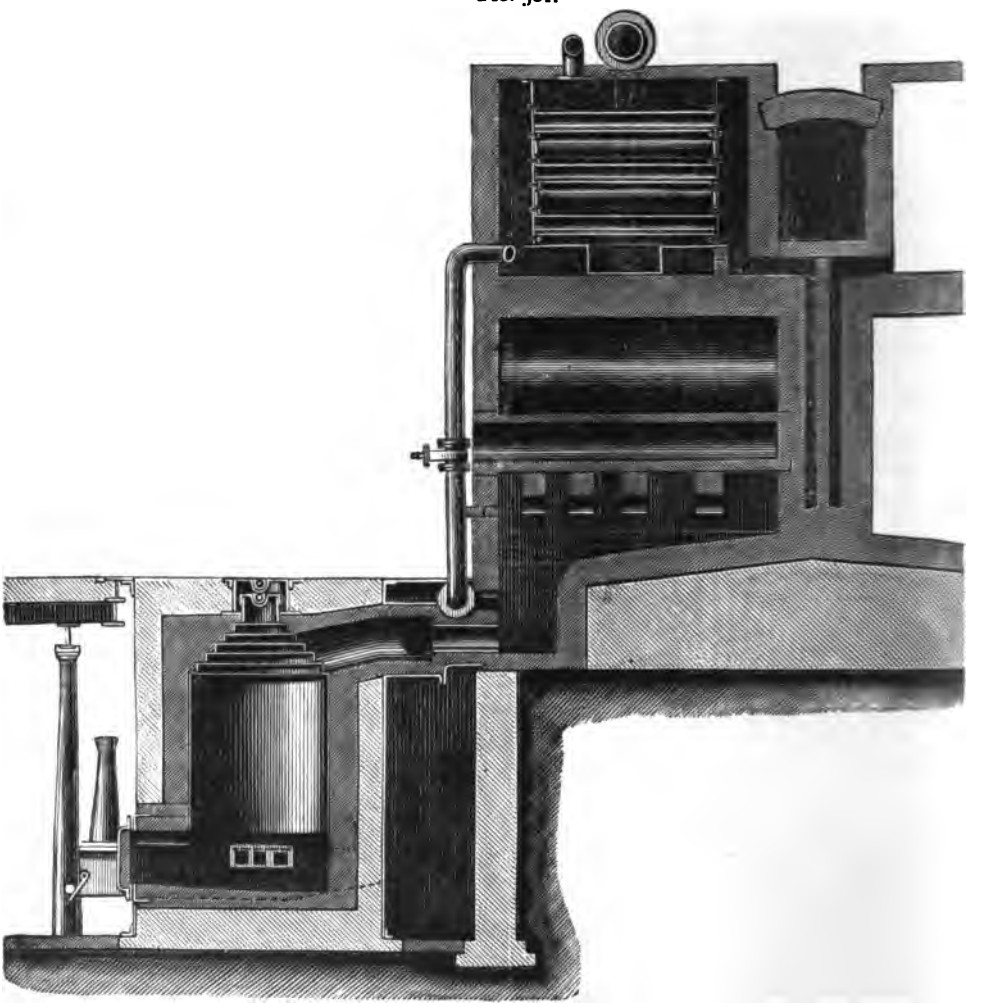
similar in principle to that described under Evaporation is employed, proper measures being taken to condense and collect the vapour; and this has been applied in a modified way to the manufacture of coal-gas.

When the substances to be distilled require a very high temperature, which metal vessels are unable to withstand, fire-brick ovens are employed.

This is the case with pitch, which is distilled in the ovens shown in Fig. 503, a full description of which will be given in another volume. The furnaces and flues are below the ovens, the smoke passing by an underground flue to the chimney. The cast-iron pipe through which the volatile products escape is shown at the top of one of the ovens.

Drying.—The removal of the last portions of moisture from manufactured goods is an operation necessarily connected with the application of fuel, in all those countries at least where the climate is changeable, and

FIG. 501.



simple exposure to the air and sun cannot be resorted to, or are insufficient for the purpose. Indeed, so irregular and uncertain is the system of open-air drying, that it is not adapted for manufactures, where definite quantities of goods are produced every week throughout the year. A current of warm air is generally considered the most effective drying agent, the apparatus for heating the air being placed either outside the drying chamber, or in

FIG. 502.

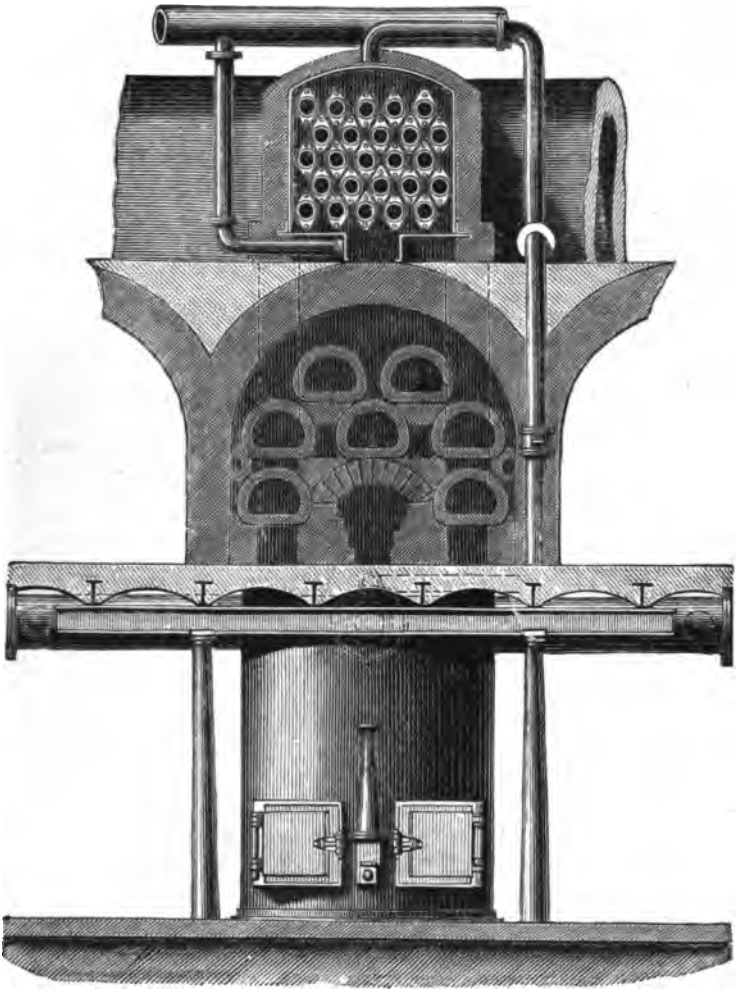
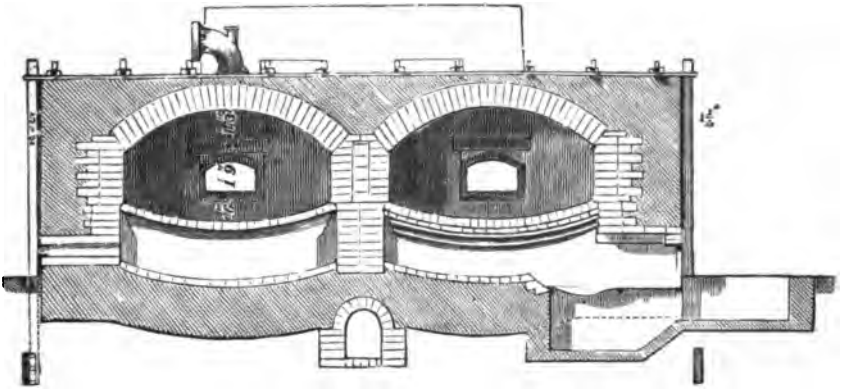


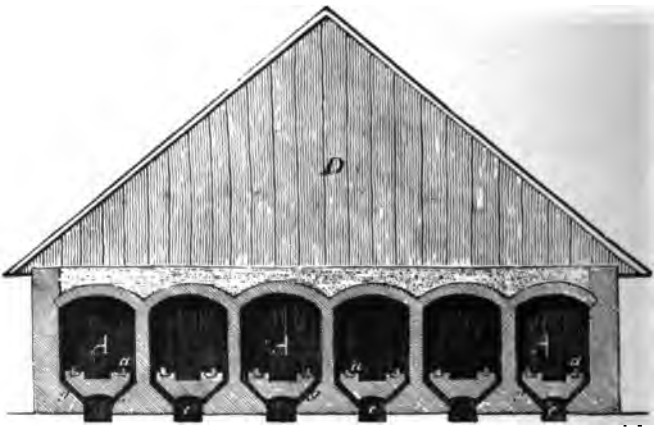
FIG. 503.



the interior. From the known quantity of aqueous vapour which air is capable of taking up at different temperatures, and the amount of moisture to be expelled in a given time, the quantity of air to be supplied in each special case can be calculated; the size of the drying-chamber and the diameter of the vapour chimney being adapted to the size of the heating apparatus and the amount of fuel consumed. When the substances to be dried are of such a nature as to remain uninjured by the air which has passed through the fire, and is mixed with carbonic acid gas and more or less smoke and dust, the fire may be made below the drying chamber, and the products of combustion allowed to pass into it, care being taken to place the fire at a sufficient distance to prevent the danger of igniting the substances to be dried. Where smoke is prejudicial, anthracite or coke may be employed as fuel.

In far the greater number of drying operations, however, the products of combustion, and the dust and ashes with which they are necessarily mingled, are highly injurious, and hot-air stoves, or pipes conveying steam or water, applied in the manner described in the foregoing pages, must be employed for heating the current of air. The drying-house should be constructed of badly conducting materials to prevent loss of heat by the walls, and contain

FIG. 504.

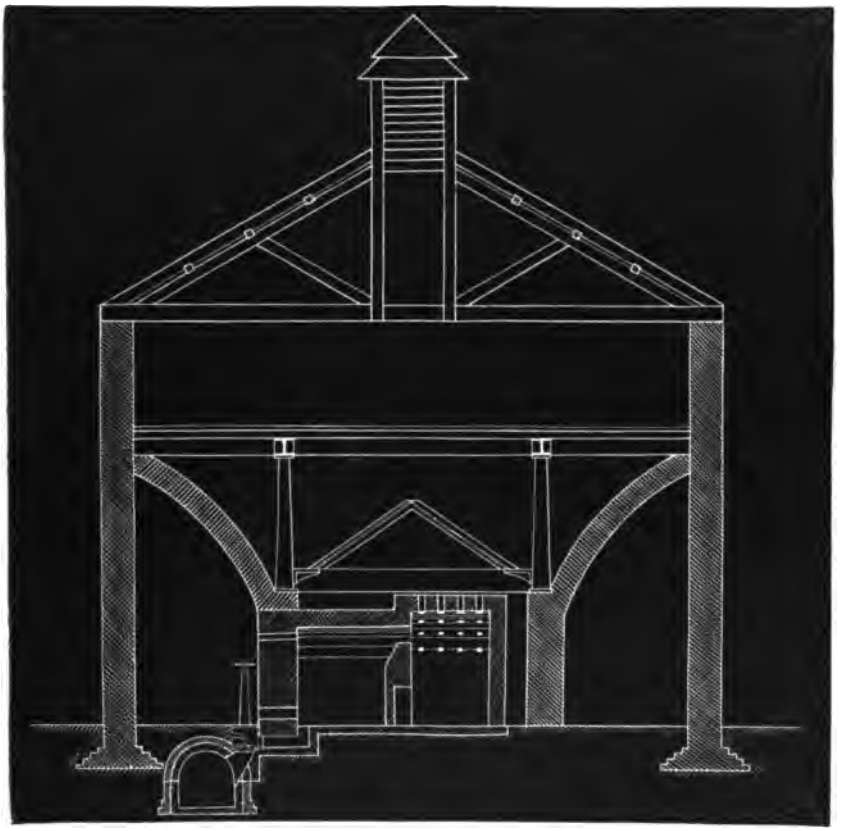


no permanent apertures but those for the entrance and exit of the air current, the doors for the introduction of the goods being securely closed during the operation. The size of the drying-room should be so proportioned to the work to be done, that the air at its exit is completely saturated with moisture, and the substances so arranged as to expose the greatest possible surface to the air current, whilst no air saturated with moisture is allowed to remain stagnant in any part of the chamber. From 7 to 10 feet is a convenient height for the chamber, and a very great advantage is gained by causing the hot-air current to enter at the upper part, and escape from the level of the floor. The velocity of the current is thus retarded, and time allowed for its perfect saturation, whilst partial currents and consequent stagnation in certain regions of the chamber are avoided, which almost invariably occur when the current passes rapidly in an upward direction. Several vapour chimneys for discharging the saturated air often produce a better distribution of the hot current than a single vent, and it is frequently necessary to cap them with a movable cowl, which, turning with the wind, allows the vapour to escape more easily. The draught may often be secured and augmented by connecting the vapour discharger with the chimney of the heating apparatus.

Fig. 504 shows a series of drying chambers employed for drying wood for the use of glass houses in France. The six chambers *A A A* are each 60 feet long, 6 feet broad, by 5 feet high; they are arched over, and the whole of them covered by a single roof. There is a fire at each end of every chamber, and the products of combustion are allowed to enter by the passages *g g* into the body of the kilns at some distance from the grates. The wood to be dried is placed upon trucks, which travel on the rails *a a*.

The system usually practised by bleachers and others in this country for drying their goods, is by an intermittent saturation of the air contained in the drying chamber. The chamber is built over a furnace, the metal flue from which extends through its entire length. The goods being introduced,

Fig. 505.

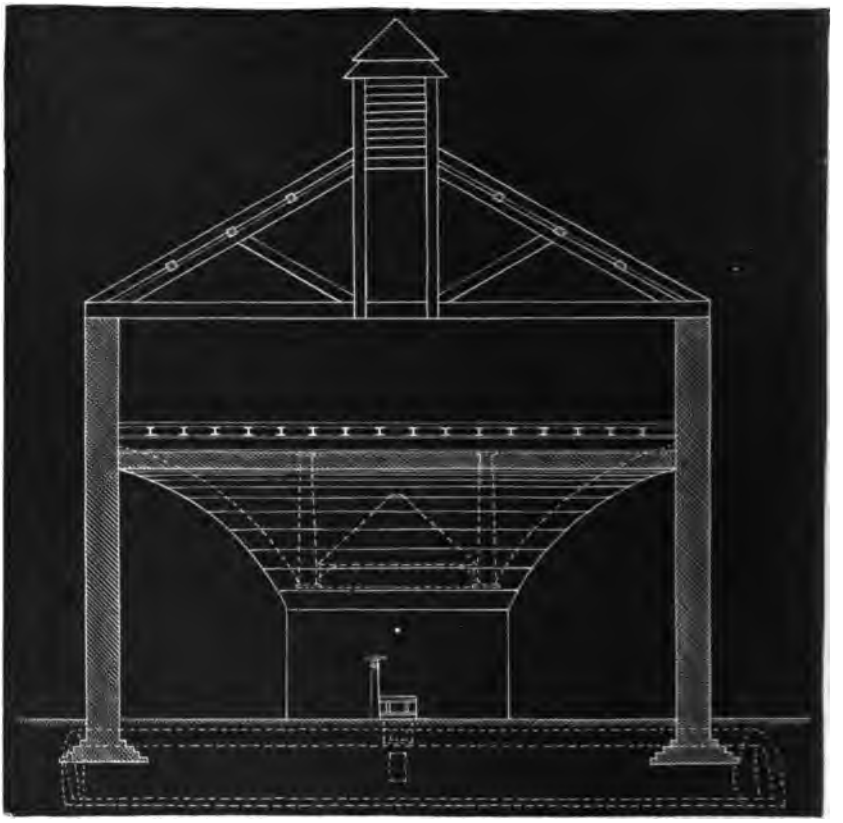


the chamber is kept carefully closed until the air has become saturated with moisture, which may be observed by a window in the side becoming distinctly covered with dew. The door and louvres or shutters in the top are then opened, when the moist air is discharged, and a fresh supply admitted. This operation is repeated until the goods are sufficiently dry. Although this is a very simple method, it not only involves a considerable loss of heat, but the goods are only imperfectly dried.

Kilns are employed for drying malt, into which the products of combustion from a charcoal, coke, or anthracite fire are carried, with a large body of warm air, through a perforated metal floor, upon which the malt is lightly spread out. The modern form of malt-kiln arranged with a gas fire

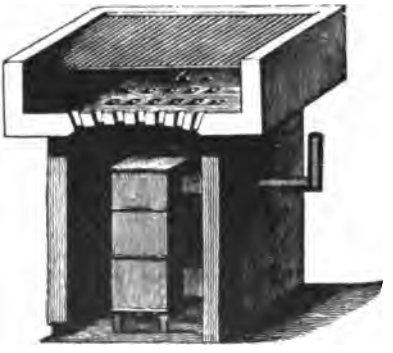
is shown in Figs. 505, 506. Sometimes a current of warm air only is employed, while the smoke and heated gases from the fuel are removed by a

Fig. 506.



flue. This arrangement of the malt-kiln may be seen from Fig. 507, where the air, heated by the stove, ascends through the perforations in the floor above it, upon which the malt is placed. In the large breweries of Bavaria the malt is dried in the manner shown in Fig. 508, by warm air.

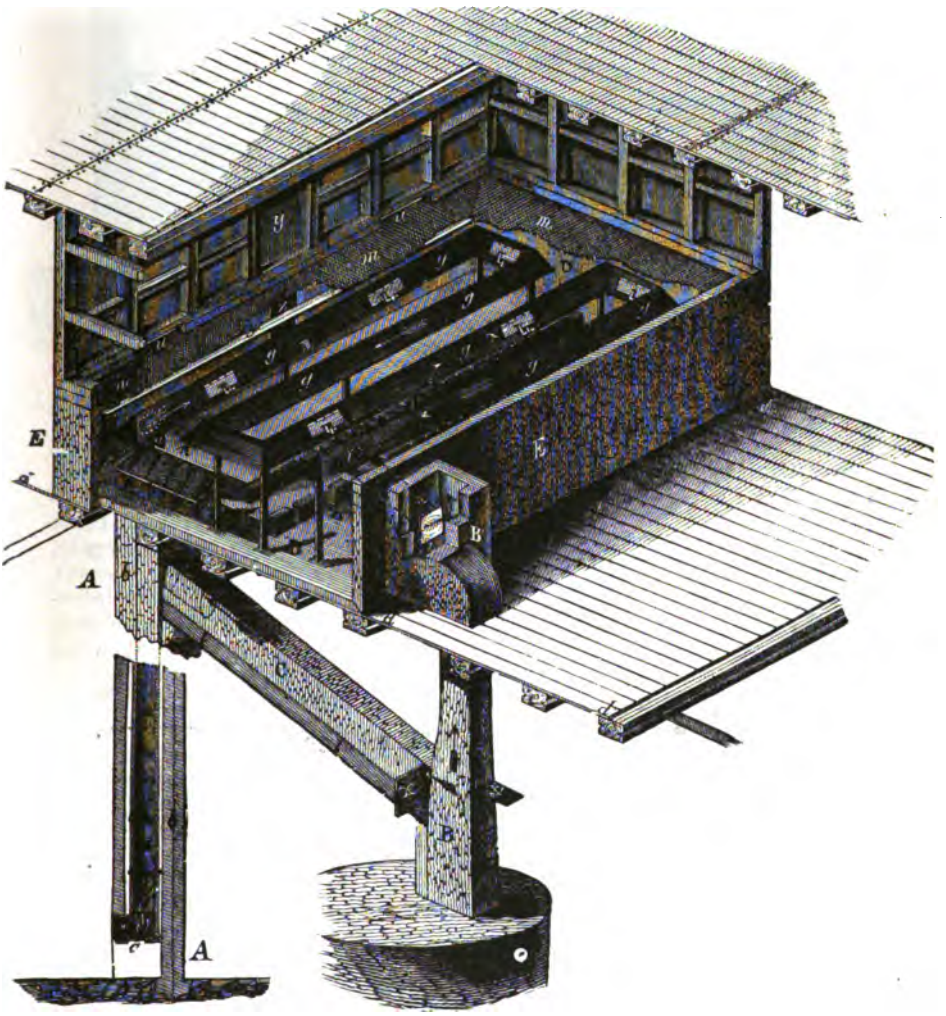
Fig. 507.



A is the fire for heating the drying floor, which is often assisted by the waste heat from the boiling-furnaces supplied through *B*. The iron cylinder which conveys the smoke and heated gases from the fire, communicates with the triangular horizontal metal flue *g g g*, passing in a zigzag manner under the wire-gauze floor *m m*, upon which the malt is placed. After circulating in this flue, the smoke escapes through the chimney at *B*. The dampers *x* and *x'* in the flue *B* enable the smoke from the boiling-furnaces to be carried either directly to the chimney or through the flue *C* to the malting-floor.

Air enters the flue *b b* which surrounds the smoke-pipe *a*, and is conducted by a series of half-open channels, constructed with bricks, on the floor of the drying-chamber, below the horizontal flue *g g*. These channels are higher on the one side, and are covered with tiles in a slanting direction, to prevent any particles of malt from falling into them. The air thus warmed by contact with the smoke-flue, passes through the malt and dries it. The wire-gauze bottom, over which the malt is spread out, is supported by bars of iron.

Fig. 508.

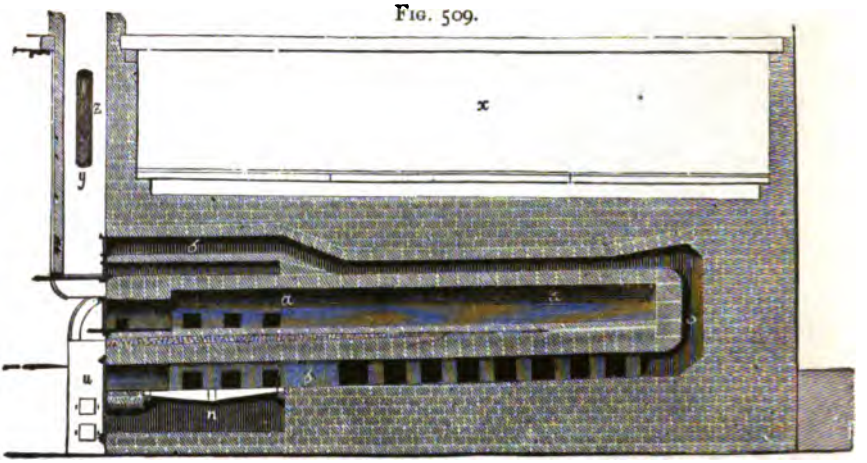


The methods of drying manufactured goods by exposure to the radiant heat of the surfaces of channels through which smoke or steam is passing, and the centrifugal application now so universally employed, involve no novel application of fuel.

Baking, Annealing, Calcining, &c.—Ovens and kilns are used for a great variety of purposes in the arts, and are modified in form and construction to suit the different objects in view.

In some operations, it is necessary carefully to separate the objects to be baked or heated from the fuel and products of combustion; while in others, the contact of these with the fuel and smoke is attended with little or no inconvenience, and sometimes is even absolutely necessary. Most of these operations differ from simple processes of drying, by the change of

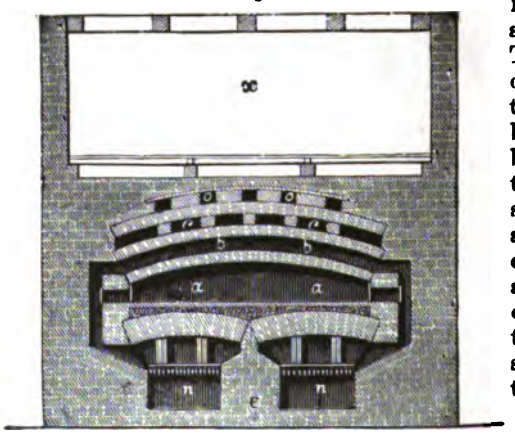
Fig. 509.



chemical composition which the high temperature employed induces in the objects exposed to it.

The ovens employed for baking bread are still very commonly heated by wood, which is placed upon the sole of the oven itself, flues being introduced at the back for carrying away the smoke. When the charge of wood is completely consumed, these flues are stopped by dampers, and the ashes are removed. The bread is then introduced, and the oven closed, the accumulated heat in the brickwork being sufficient to bake the bread. The operation is in this case necessarily interrupted each time a baking is completed, and coal should not be employed as fuel, on account of the dirt it produces, although the flame from a coal fire is still often admitted to heat the oven.

Fig. 510.

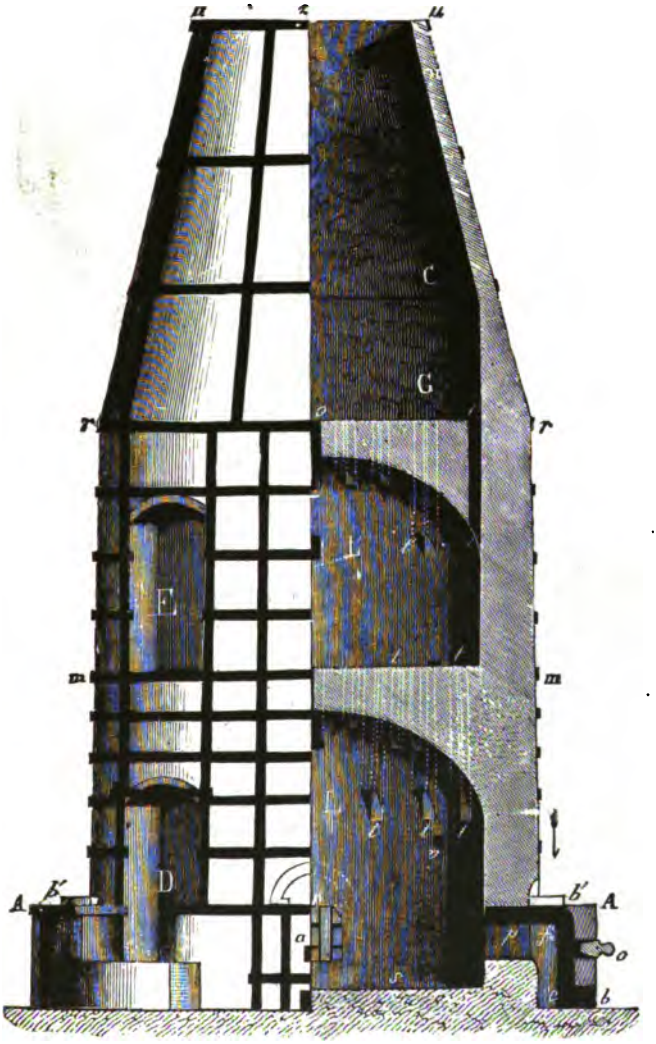


Figs. 509 and 510 show sections of a large oven, in which the fuel is not admitted into the interior, and which admits of an uninterrupted process. Coal is burnt on the grates at *n n*, and the smoke and heated gases from its combustion passing through a series of arched flues below the sole of the oven *a a*, return again by the flue *b* over the top to the chimney *y*. In the front of the oven, which is less exposed, distinct flues convey a portion of the flame into the oven, or over it, as may be required, while a series of pipes in connection with the flues *o o* carry off the vapour rising from the loaves in baking.

In baking porcelain and pottery, a very high temperature is required, while the objects exposed to it must be carefully protected from the smoke and dust of the fuel.

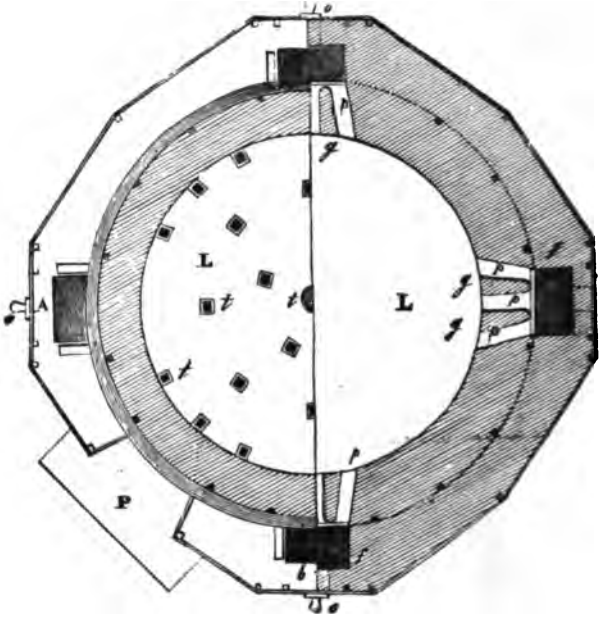
Figs. 511 and 512 show the construction of a porcelain kiln. Four separate fires, *A A A A*, discharge the flame and products of combustion into the body of the kiln *L L'*, in which the goods are carefully packed in

FIG. 511.



protecting vessels called seggars. The fires have no grates, but, the space *e* being filled with red-hot charcoal, wood is introduced through the aperture *b'*, until the entire space *f* is filled with fuel. Air is supplied through *b'* in the downward direction indicated by the arrow, and has therefore to pass through a great body of ignited fuel before reaching the body of the kiln; cold air is thus excluded, and more perfect combustion secured. The flame is separated into three distinct portions, passing through the flues *p p p*.

Fig. 512.



The different stages in the kiln *L L'* and *G* are connected by numerous apertures *t t t*. In the lowest, where the greatest heat prevails, the final baking of the ware is effected; whilst the upper stories are used in the earlier parts of the process of manufacture.

Fig. 513.

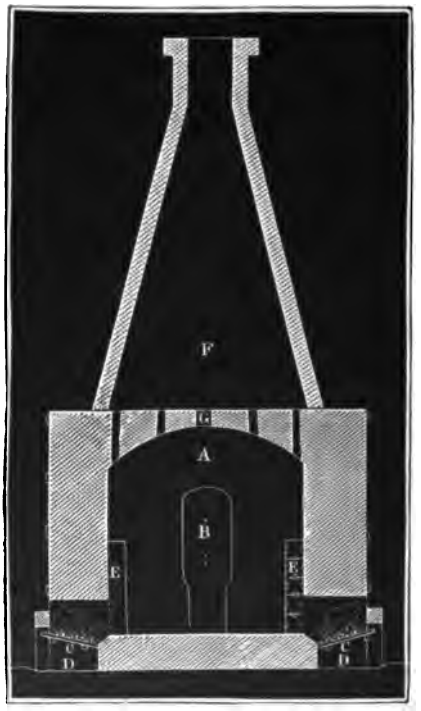


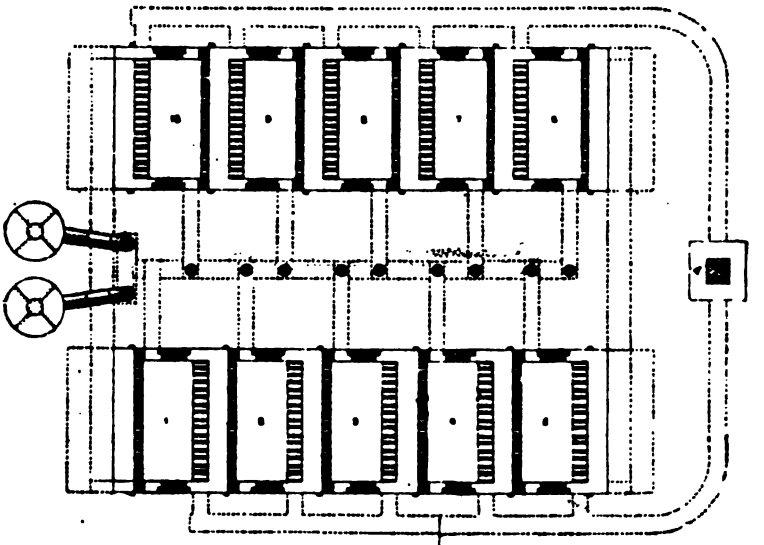
Fig. 513 represents a kiln employed for baking stoneware in the Lambeth potteries. Coal being the fuel consumed, a slanting grate, shown at *c*, is employed, which is fed from above in such a manner that the air is forced to pass through and over the burning fuel. Five of these grates are placed at equal distances round the body of the kiln, a perforated chimney, or *bag*, of brickwork, being placed opposite each fire to separate the flame at its entrance to the kiln.

Gas-fired Kilns.—The problem of applying gas firing to kilns for burning fire- and other bricks, and probably for pottery also, has been solved in a practical way very successfully by the patent regenerative kilns of Mr. James Dunnachie.*

* See paper by John Mayer, F.C.S., "Trans. Inst. Engin. and Shipbuilders in Scotland," vol. for 1885.

Formerly, the large amount of heat absorbed by bricks and pottery in the process of burning was uselessly dissipated during the cooling of the kilns and their contents, but in the Dunnachie kiln it is used to heat up the air

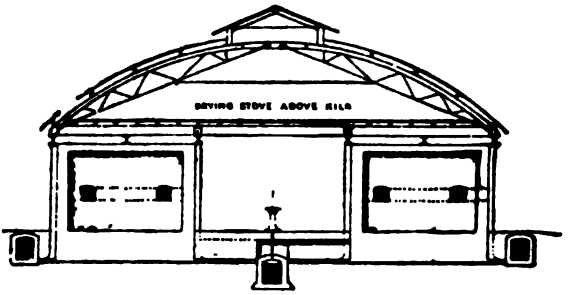
Fig. 514.



Ground Plan.

required for combustion of the gas, and thus a chamber of burned bricks or ware serves the same purpose, and has exactly the same function, as a regenerator chamber in a Siemens furnace.

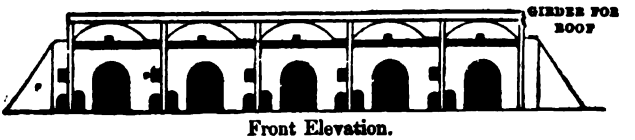
Fig. 515.



Cross Section.

Figs. 514–517 illustrate this kiln, which consists of a series of chambers placed side by side. Fig. 517 is a longitudinal vertical section through one set of five chambers. The gas, which in the case of all the kilns first introduced and worked on this system, was supplied under a positive pressure from "Wilson" producers, is admitted through the flue *A*, and passes into the burner *B*, where it meets with the hot air from the adjoining chamber entering by the flue *F*. From the flue *C*, the draught may be passed on, either into the next chamber, or to the chimney, as may be desired. By this arrangement, the waste heat is utilized in the unburned chambers in advance, which are thus

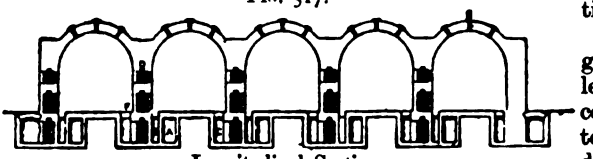
Fig. 516.



Front Elevation.

heated up preparatory to full firing, while the heat of the chamber which has been "burned off" is transferred by the air-supply traversing it to the place of combustion.

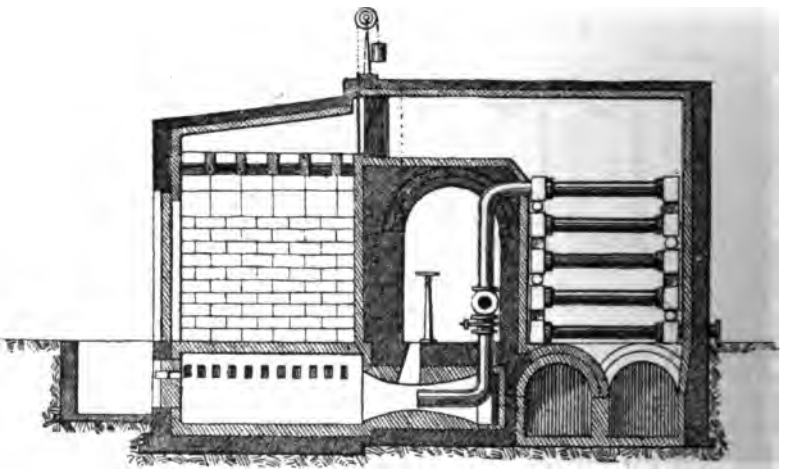
Fig. 517.



Longitudinal Section.

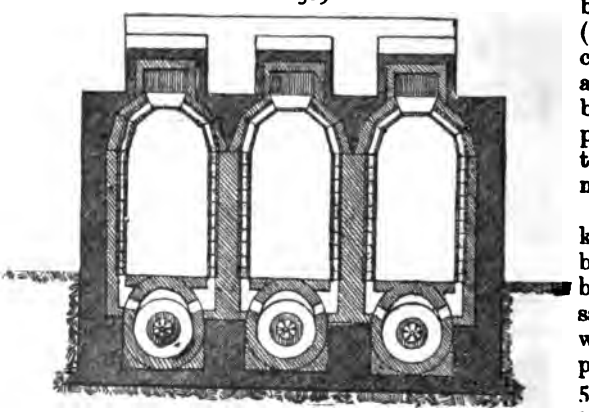
The hot air and gas meet at the floor level, when there is combustion at a high temperature produced. Both air and gas, being governed by regulating valves, may be varied in quantity and proportion to the requirements of any special case. The flue *D* is provided in order to admit

Fig. 518.



air to any chamber at a higher level than that of the main supply from *F*, and is used either for exhausting the heat from the higher layers of bricks in a burned-off chamber, or for tempering (by the admission of cold air) the heat in a chamber which is being burned, so as to prevent the front of the bricks being too much burned.

Fig. 519



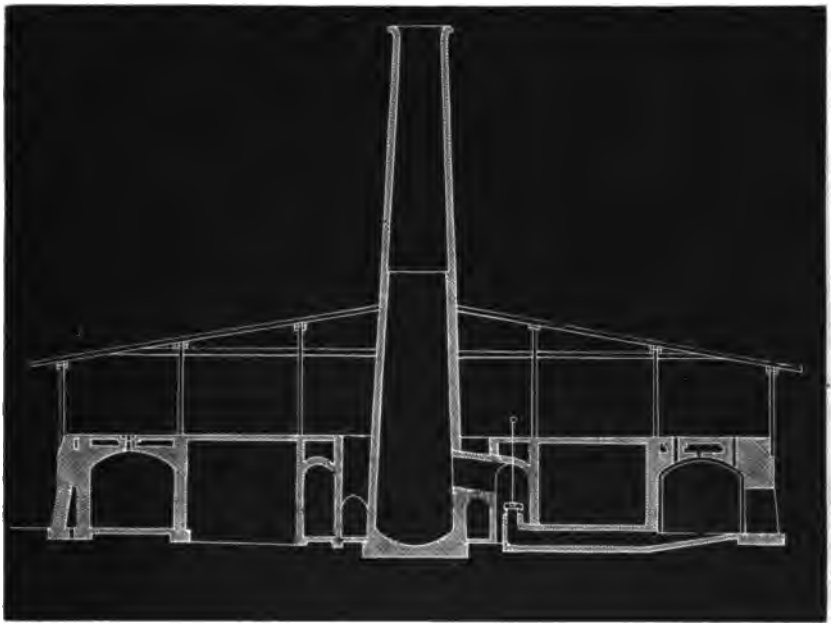
By means of these kilns, fire-bricks are burned at the Glenbrig Works more satisfactorily, and with a saving of 75 per cent. in fuel and 50 per cent. in time as compared with coal-fired kilns. There is also a saving in labour and in the wear of the kilns.

Figs. 518, 519, illustrate a kiln or muffle successfully used at Linthorpe

Pottery for glazing art pottery. In this case, continuous regenerators of cast iron, formed into a coil or stack of pipes, were used, the air-supply being propelled through these pipes by a fan, and meeting the gas from the producers at one end of the oval combustion chambers placed under the muffle. The flame and hot gases passed up on both sides of the muffle chambers and escaped by openings at the roof, whence they passed away by the flue in which the iron-pipe regenerator was placed. The only difficulty experienced in working this kiln was that of getting any material to stand the exceedingly high temperature of combustion produced by the blowpipe arrangement.

Hoffmann's patent kiln was, if not the first, certainly the first successful method of utilizing some of the heat which in old-fashioned kilns is still uselessly wasted. Consequently, this kiln was economical in working. It was, however, worked with solid fuel charged through holes in the roof into

FIG. 520.

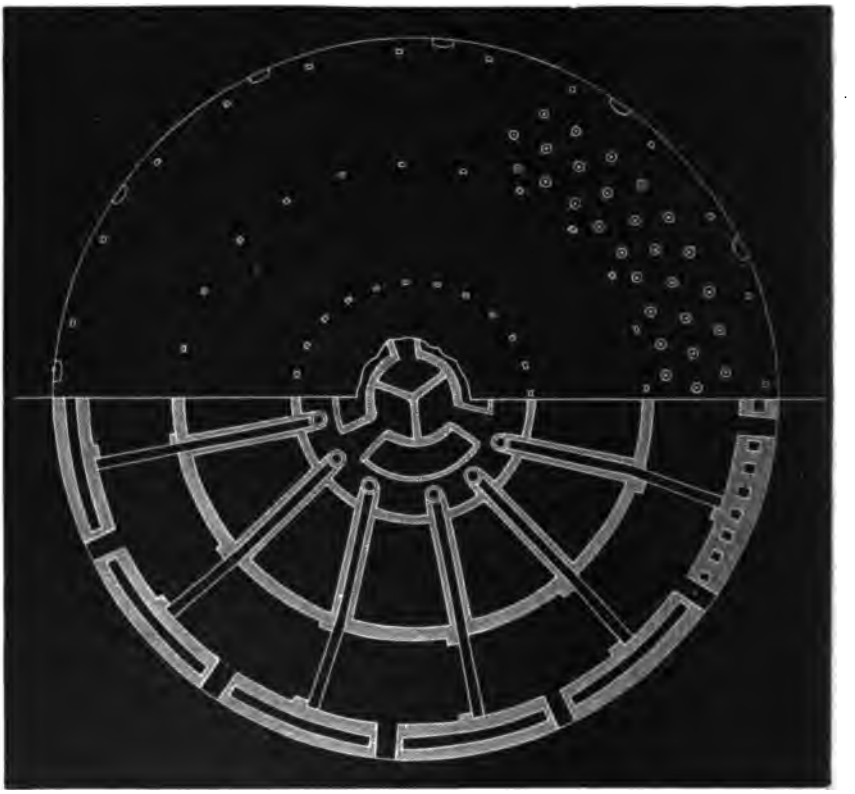


the fire-places, which were built in among the bricks being burned, and were arranged with openings to flues so that the draught and hot air could be taken in any desired direction. This kiln was, however, suitable only for red bricks. Figs. 520, 521 (which have been supplied by Mr. John Craven), illustrate this kiln arranged with twelve chambers set radially round a central chimney. Fig. 520 is in sectional elevation, and Fig. 521 in plan partly sectional.

In order to put this kiln in operation, all its compartments are filled with green bricks, except one, which is left empty for the purpose of commencing the firing from below in the ordinary way by fires made in a brick wall temporarily built across the burning chamber in front of the bricks set in the kiln for burning. When these fires have caused the bricks in the first one or two compartments next to the temporary wall to become red hot, the firing is continued from above by dropping coal through the feeding-holes in the arch of the kiln.

If, in setting a kiln to work, the temporary wall is built between chambers 12 and 1, chamber 12 is left empty, a damper is built between chambers 11 and 12, and the setting of green bricks is begun in chamber 11. When 11 is filled, its doorway is closed, but a small fire-hole is left in it at the floor level, where a fire is made to drive off the moisture from the bricks, the valve of chamber 11 being opened to draw off the moisture with the smoke. Then chamber 10 is filled with bricks, and its doorway closed in the same manner as that of chamber 11; a small fire is made in it, as in the former case, and its valve opened. In this way the filling of the chambers with bricks goes on in the direction opposite to that in which afterwards the fire will take its course, until at last chamber 1 is

FIG. 521.



filled with bricks, when the temporary brick wall already mentioned is built up in front of it across the kiln with as many fire-places as there are rows of feed-holes in the arch of the kiln. Small fires are lighted in these fire-places, and therefore no fire is required in the doorway of No. 1. The firing in these fire-places is continued slowly for some days, so that the green bricks and the kiln walls are dried and gradually heated, when they can be exposed to an intense heat.

The feeding-holes in the arch of the kiln are covered by caps, which are removed as long as steam or warm air is escaping by them, but must be replaced if air is drawn into the kiln through the holes.

Before the fires in the temporary brick wall are increased, the small fires in the various doorways are allowed to go out, and the doorways are

entirely closed in succession, beginning with No. 2 and advancing towards No. 11, the corresponding valves also being closed, at intervals of about twelve hours between each. The valves of chambers 10 and 11 remain open, so that the fire in the doorway of 11 burns longer than any of the others, and is not put out till the bricks in this chamber have become thoroughly warm.

The fires in the brick wall in front of chamber 1 are now increased to the desired temperature. When the bricks in chambers 1 and 2 have become red hot, the firing from above through the feed-holes in the arch is commenced in these two chambers. The red heat advances from chamber 2 into chamber 3, and so on, the firing from above being commenced in each as soon as the fire-holes are red from top to bottom.

When the firing has been commenced in chamber 3, the fires in the brick wall in front of chamber 1 are slackened, but small fires are kept up until the firing from above has advanced to chamber 4, when it is stopped in chamber 1, and the fire-places in the wall are closed with bricks. At the same time one, and soon afterwards a few more feed-holes of chamber 1 are uncovered, to let the requisite air for combustion pass through them into the kiln. Firing from above has now been stopped in chamber 2, and the bricks in the two first chambers are now cooling off.

In order to admit more air into the kiln, so that combustion may become more rapid, the temporary wall is gradually taken down, until, when chambers 5 and 6 are fired, the wall is altogether removed. As the heat advances in the kiln, firing from above also advances with it, while at the same time it is discontinued in the rear in equal ratio, but always at a distance of about two chambers which are being fed with coal. When the firing commences in 7, the bricks in 1 are taken out, and chamber 12 is then filled with green bricks. The damper is now removed to between 12 and 1, and the doorway of 12 is closed. When firing is commenced in 8, the burned bricks are similarly removed from 2, and chamber 1 is filled with green bricks, the damper being now placed between 1 and 2. This sequence is followed round the circle, one chamber being emptied of burned bricks and one filled with green bricks every day, care, however, being taken that the bricks in the last filled chamber are perfectly dry before the damper is removed.*

Mr. Herbert Guthrie, C.E., also introduced a very interesting continuous kiln in which the waste heat was made use of. This, although called a "gas kiln," was not strictly gas fired, as there was a fire-place for solid fuel to each chamber. The waste gases were passed into a second chamber, so as to heat it up preparatory to full burning, and the waste heat in a burned-off chamber was made use of to heat the air, which was passed through the fire of the one in advance. There is no doubt that a very strong heat would be thus economically produced, but the full advantage of gas firing could not be obtained by this plan in spite of its great ingenuity.

A most interesting paper on its application to burning pottery was published by Mr. Guthrie in the Journal of the Society of Arts, vol. xxviii., February 20, 1880.

Fig. 522 represents what Mr. Guthrie calls a sectional perspective of his kiln showing nearly every part of it. The chambers in which the goods are placed are indicated by the letter *A*, the gas producers by the letter *G*, the flue leading to the chimney by the letter *L*, and the wickets by the letter *W*. In making this arrangement, Mr Guthrie kept the following points in view:—First, that the form of the chambers should be no departure from those in general use and proved to be of good shape and propor-

* An improved chamber kiln for bricks, lime, and cement, of the Hoffmann type, called the "Hertrampf," is described in "Industries," November 12, 1886, pp. 512, 513.

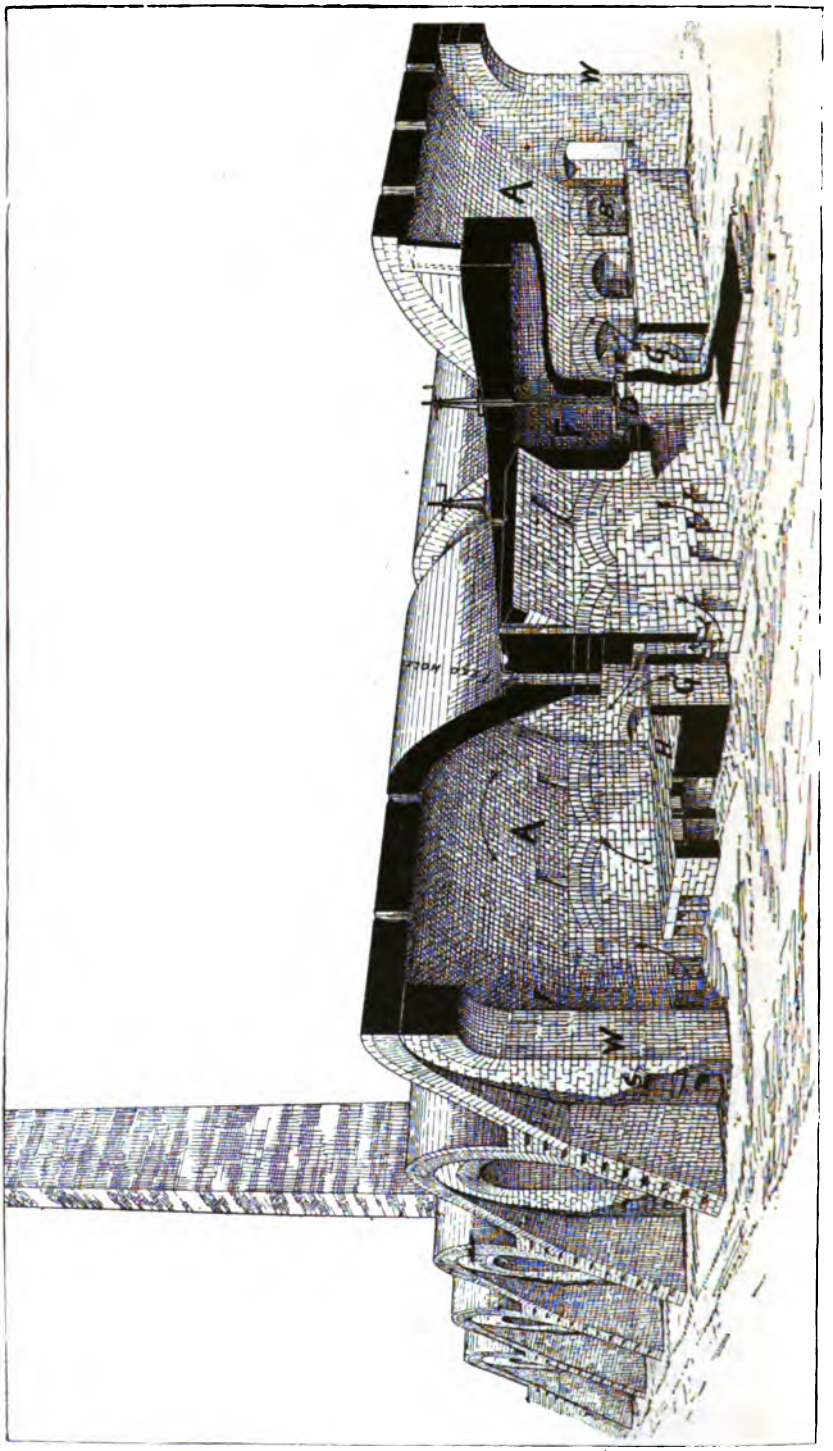


Fig. 522.

FIG. 523.

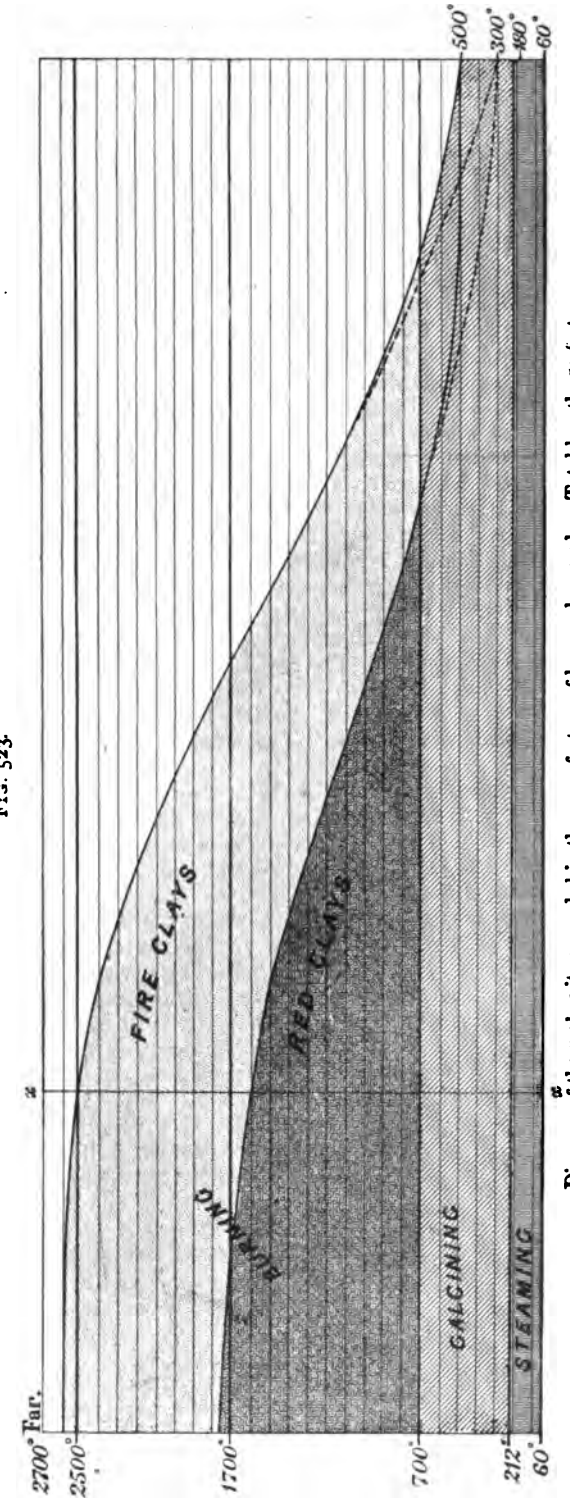


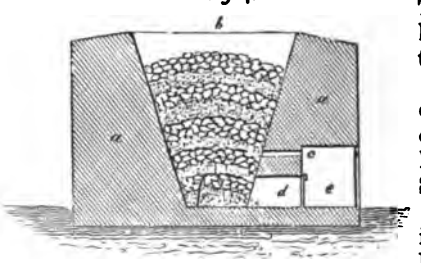
Diagram of thermal units expended in the manufacture of heavy clay goods. Total length, 50 feet.

tion; secondly, that the heat should rise from a similar position within those chambers; and, thirdly, that the draught should take the same course through the goods. The *modus operandi* is this: The goods having been placed in several chambers and the wickets made up, fires are kindled in the gas producers, and the process of steaming, calcining, and burning carried on in much the same way as usual. Rather open fires are worked at first, with plenty of air, gradually making it hotter, and limiting the air as the successive stages are completed. At the beginning of the burning stage, however, the fires are made deep and close, working them like a gas producer instead of an open fire, and filling them up until the fuel touches and perhaps rises slightly above the sill of the air-port shown at the back of the producer in the division wall. By this means the amount of air can be regulated by the fuel; for if the air-port be partly closed and there is a good draught on the kiln, it is evident we can force more or less air through the body of the fire, and maintain a perfect control.

Mr. Guthrie has carefully analysed and estimated the expenditure of fuel in the manufacture of heavy clay goods, on the basis that 100 lbs. of prepared clay contains 37 lbs. of water free and combined, and has graphically expressed his analysis by the diagram shown in Fig. 523. The perpendicular line represents degrees F. as well as feet, and the horizontal line feet only. The space embraced by the two perpendicular lines on the left of the diagram represents the extent of an ordinary kiln, and the total length of the diagram represents that portion of a continuous kiln which is occupied by the progressing part of the heat. The firing is supposed to take place at the extreme left, and the curved lines to show the temperature at any given point. The first division at the bottom shows the steaming stage; the next indicates the calcining stage; the division above that, the first burning stage; and the two upper divisions, the burning stage of the more refractory goods. The total length is supposed to be 50 feet.

"If we test a continuous kiln," Mr. Guthrie remarks, "we shall find the temperatures not very far from those indicated in the diagram by the curved line; therefore, if we calculate the area of the burning stage beyond the intermediate perpendicular line (x) and the end, and enclosed between the curved line and the exit temperature line, we find that amount of heat utilized which must be the amount that would otherwise have gone up the chimney. The deduction for loss by conduction and radiation, however, has not been made; lines, therefore, showing the actual temperature would be below these. In my calculations so far, the temperature of the exit gases is supposed to be 500°. This, however, is found to be much higher than is necessary for a continuous kiln of good construction."

Fig. 524.



Mr. Guthrie's analysis of the expenditure of fuel is given in an elaborate table, which we copy from his paper in the Journal of the Society of Arts.*

In the kilns employed for burning or expelling the water and carbonic acid from limestone, the fuel is generally stratified with the limestone in the manner shown in Fig. 524. The kiln being once fired, the combustion is kept up by the consecutive layers of coal, and the lime is drawn at intervals from the bottom of the kiln. It is probable that a similar arrangement to that introduced by

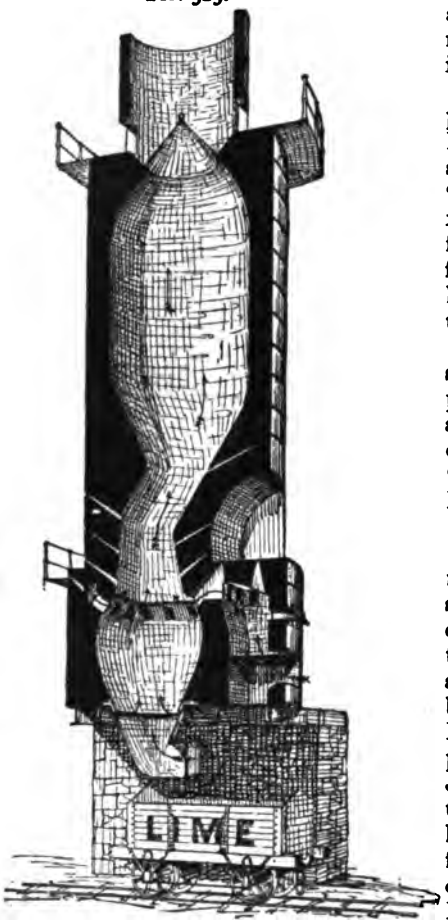
* "Jour. Soc. Arts," 1880, p. 239.

TABLE SHOWING ANALYSIS OF EXPENDITURE OF FUEL IN THE MANUFACTURE OF HEAVY CLAY GOODS, 100 LBS. OF PREPARED CLAY CONTAINING 37 LBS. OF WATER, LOOSE AND COMBINED.

	Progress of 100 lbs. of Prepared Clay through the Several Stages.	If thoroughly dried.				If partially dried.			
		Thermal units per 100 lbs.		Cwts. per 1,000 bricks.		Thermal units per 100 lbs.		Cwts. per 1,000 bricks.	
At 6,000 thermal units per lb. of fuel.	DRYING—								
	To raising 63 lbs. clay from 50° to 150° F. .	1,260.0		0 0 26.1		1,260.0		0 0 26.1	
	To raising 37 lbs. water „ „ .	3,700.0		0 2 20.7		3,700.0		0 2 20.7	
	To evaporating 29 and 24 lbs. water respectively	28,014.0		5 0 21.0		23,184.0		4 1 4.8	
			32,974.0		6 0 11.9		28,144.0		5 0 23.7
	STEAMING—								
	To raising 63 lbs. clay from 60° to 212° F. .	1,915.2		0 1 11.7		1,915.2		0 1 11.7	
	To raising 8 and 13 lbs. water „ „ .	1,216.0		*e* 0 0 25.2		1,976.0		*g* 0 1 12.1	
	To evaporating 4 and 9 lbs. water respectively	3,864 0		*f* 0 2 24.1		8,694.0		*h* 1 2 12.3	
			6,995 2		1 1 5.1		12,585.2		2 1 9.0
	CALCINING—								
	To raising 63 lbs. clay from 212° to 700° F.	6,148.8		*a* 1 0 15.5		6,148.8		1 0 15.5	
	To raising 4 lbs. water „ „ .	1,952.0		*b* 0 1 12.5		1,952.0		0 1 12.5	
	To evaporating 4 lbs. water . . .	3,864.0		0 2 24.1		3,864.0		0 2 24.1	
			11,964.8		2 0 24.1		11,964.8		2 0 24.1
	Difference, 760 thermal units = 15.76 lbs. of fuel		51,934.0		9 2 13.1		52,694.0		9 3 0.9
	Deducting the drying		32,974.0		6 0 11.9		28,144.0		5 0 23.7
			18,960.0		3 2 1.2		24,550.0		4 2 5.2
At 5,500 thermal units per lb.	BURNING—								
	To raising 63 lbs. clay from 700° to 1700° + 100 per cent. of waste	25,200.0	25,200.0	*c*	5 0 10.0				5 0 10.0
	Total spent in common kilns . .		44.160.0		8 2 11.2				9 2 15.2
	Amount wasted and recoverable = $\frac{1}{3}a+\frac{1}{3}b+c$		28,440.3		5 2 21.3				5 2 21.3
	Total spent in good continuous kilns .		15.719.7		2 3 17.9	$\{-(\frac{1}{3}e+\frac{1}{3}f)=$			3 3 21.9
	Or again for more refractory goods . .		18,960.0		3 2 1.2	$-0\ 1\ 7.1\}=2\ 2\ 10.8$		$-(\frac{1}{3}g+\frac{1}{3}h)=$	0 2 17.5
At 5,000 thermal units per lb.	To raising 63 lbs clay from 700° to 2500° + 150 per cent. of waste		56,700.0	*d*	12 2 11.3				3 1 4.4
	Total spent in common kilns . .		75,660.0		16 0 12.5				
	Amount wasted and recoverable $\frac{2}{3}a+\frac{2}{3}b+$ (d – 20 per cent.)		48,600.3		10 2 20.3				
	Total spent in good continuous kilns .		27,959.7		5 1 20.2	$-0\ 1\ 7.1=5\ 0\ 13.1$			

Mr. Dunnachie for burning fire-bricks, described on pp. 627, 628, would make the best lime-kiln also. Where wood and turf are employed as fuel, an arrangement similar to that employed in the potter's kiln is adopted.

Fig. 525.

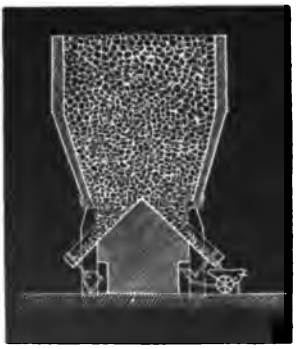


Mr. Herbert Guthrie, C.E., has proposed the form of kiln shown in Fig. 525, in which the fuel is kept separate from the limestone (see "Jour. Soc. of Arts," No. 1432, vol. xxviii., Feb. 20, 1880), and the air for combustion of the gases issuing from the producer alongside is heated by being drawn up through the burned lime which is cooling.

This, with the difference of a separate gas-producer, is a similar plan to that proposed in 1878 and 1879, in a series of articles on Calcination, in the journal "Iron";* see also "Proc. Cleveland Inst. Engineers," June 9, 1879, p. 242. These articles, however, deal principally with the calcination of iron ores by gas, but describe the heating of the air for combustion by passing it through the hot stone which has been burned and is cooling. The mere burning by gas was carried out at Coltness Ironworks in 1851 or 1852 (see p. 228, and "Practical Mechanic's Jour." for April 1852). Regenerative calcining kilns worked by gas have been introduced in Sweden for calcining the Dannemora iron ore. (See "Jour. Iron and Steel Inst." No. 1, 1882, p. 408.)

Furnaces.—The furnaces employed for the various purposes of metallurgy, &c., are essentially of two kinds: first, those in which the fuel is brought into direct contact with the substance to be operated upon; and, secondly, those in which the flame only is employed. Both may be aided by an artificial blast of air.

Fig. 526.



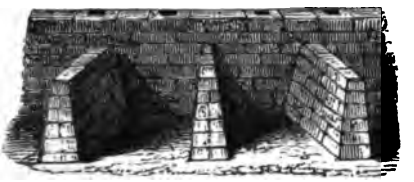
To the first-class belong the furnaces employed in many countries for roasting ores, which are in every respect similar in principle to the lime-kiln described above. The ordinary calcining kiln for iron ore used in the Cleveland district is illustrated in Figs. 526, 527. Fig. 526 being a vertical section, and Fig. 527 showing horizontal sections through the body of the kiln and through the discharging doors. The same operation is sometimes carried out in ore kilns when the mineral is of such a nature as to continue the combustion spontaneously which has been once commenced.

* "Iron," 1878, pp. 642, 674, and 706; 1879, pp. 165, 196, and 227.

Thus, Fig. 528 shows the simple kilns on which copper pyrites and the products from the first fusion of the ore, called matt, are calcined or roasted, being placed upon a bed of brushwood, which, when ignited, sufficiently heats the ore to enable the combustible matter contained in it to continue a slow process of combustion. The vacant spaces in the walls tend to increase the draught. Mr. H. Aitken, of Falkirk, introduced an ingenious method of calcining the carbonaceous black-band by a coking process. The volatile products of distillation were thus secured, and the fixed carbon left combined with the iron oxide so that it was available for reduction in the blast furnace.

Fig. 527.

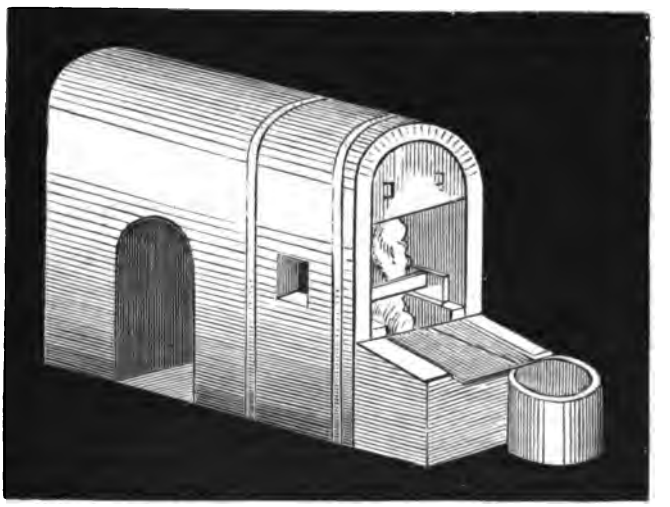
Fig. 528.



A smith's forge is, perhaps, the simplest adaptation of a blast to increase the temperature of fuel for working metals; a current of air being thrown by a bellows into the fuel where it is in contact with the metal to be heated. Much of the lead-ore in this country is melted and reduced in a furnace constructed upon similar principles, and called an ore-hearth. It is shown in Fig. 529, as improved by Dr. Richardson.

The blast enters from behind, and the flame and lead smoke, termed *fume*, are seen escaping over a bridge into a main flue at the back. The

Fig. 529.



lead-ore is thrown in through an opening at the side, with peat or coal. The temperature is not very high, and is easily regulated. Great economy of fuel is secured by the use of this kind of furnace, which is, however, only adapted for rich lead-ores.

Blast Furnace.—The blast furnace used in the manufacture of iron also belongs to the class in which the fuel is in contact with the substances acted upon by it. On this account, it might be considered as of somewhat primitive design as a heating furnace, but investigation has resulted in

demonstrating that a variety of actions on a large scale is continuously carried on in this furnace, which it is improbable could be so completely embraced in any other appliance of anything approaching the same moderate dimensions or involving the use of so little labour.

These actions include (1) saturation of the carbon of the fuel with oxygen; (2) reduction of the oxides of iron; and (3) the proper distribution of temperature for the various operations.

1. Saturation of the carbon of the fuel with oxygen involves certain limits of temperature, space, and time. Carbonic acid is first formed from the solid carbon at a high temperature in the region of the tuyères. This carbonic acid requires for its reduction to carbonic oxide a sufficient quantity of solid carbon, at a moderately high temperature, and sufficient time to traverse it, or to remain in contact with it.

2. The reduction of the ore, or oxides of iron, also demands certain limits of temperature and time. Ores vary to some extent in the readiness with which they give up their oxygen, and with respect to the temperature at which reduction takes place most readily. The carbonic acid formed by complete combustion of the carbon in the hearth, where the high temperature is required for fusion, should be reduced to carbonic oxide (as in 1), and again oxydized to carbonic acid by reducing the ore, so that in the resulting gases there should be 30 per cent. of the carbonic oxide formed into carbonic acid, or each unit of carbon as carbonic acid in the gases should be accompanied by two units as carbonic oxide.

If the temperature is too low, this result will not be attained, and, on the other hand, if the temperature is too high, ferrous oxide has the power of becoming re-oxidized by reducing in its turn the carbonic acid to carbonic oxide, and thus neutralizing the reduction from ferric oxide previously effected by means of the carbonic oxide. It has also been observed that the reduction of the oxide of iron is a heat-producing action.

3. Distribution of temperature according to the requirements of these, and some minor, operations is a question of the capacity of the furnace in proportion to the initial heat which is employed.

Whilst intense heat is required for fusion, the quantities or proportions of solid carbon and hot air used to produce this heat determine the requisite capacity of the furnace to provide space and time for heat interception above. This affects all the actions, the saturation of the carbon with oxygen, the reduction operations, and the final passing of the gases off at the proper temperature and point of saturation with oxygen.

In addition to these points, it is to be remarked that the descent of the solid materials in the furnace, and the ascent of the gases, take place automatically.

The form of the blast furnace used in the manufacture of pig-iron in Britain is shown by the sections in Figs. 530, 531, 532; one of these (Fig. 531), showing the modern form used in the Cleveland district,* and Fig. 532, showing a good specimen of blast furnace for working with hæmatite† ore. The blast furnaces in Scotland‡ and in Staffordshire rarely exceed the dimensions of the latter Fig. 532, on account of the use of raw coal, instead of coke as at Middlesbrough, as fuel in them. Coke, from superior hardness or strength, can resist a much greater crushing stress than coal is able to stand, hence furnaces charged with coke are made of much larger dimensions. At one time it was supposed that the sizes of blast furnaces might be increased with advantage almost indefinitely, and that the

* See papers by Sir I. Lowthian Bell and C. Cochrane in "Jour. Iron and Steel Inst.," and "Proc. Inst. Mech. Eng."

† Article Iron, in "Chemistry," published by Mackenzie; W. Crossley, "Proc. Inst. Mech. Eng.," 1871.

‡ F. J. Rowan, The Iron Trade of Scotland: "Jour. Iron and Steel Inst.," 1885.

same rate of increase in the production of iron would accompany every increase in size. It was found, however, that this did not hold good, and that economy of working was not attained with very large dimensions. The following series of outlines illustrates the gradual increase in dimensions and capacity which took place during a number of years. (See Fig. 530.)

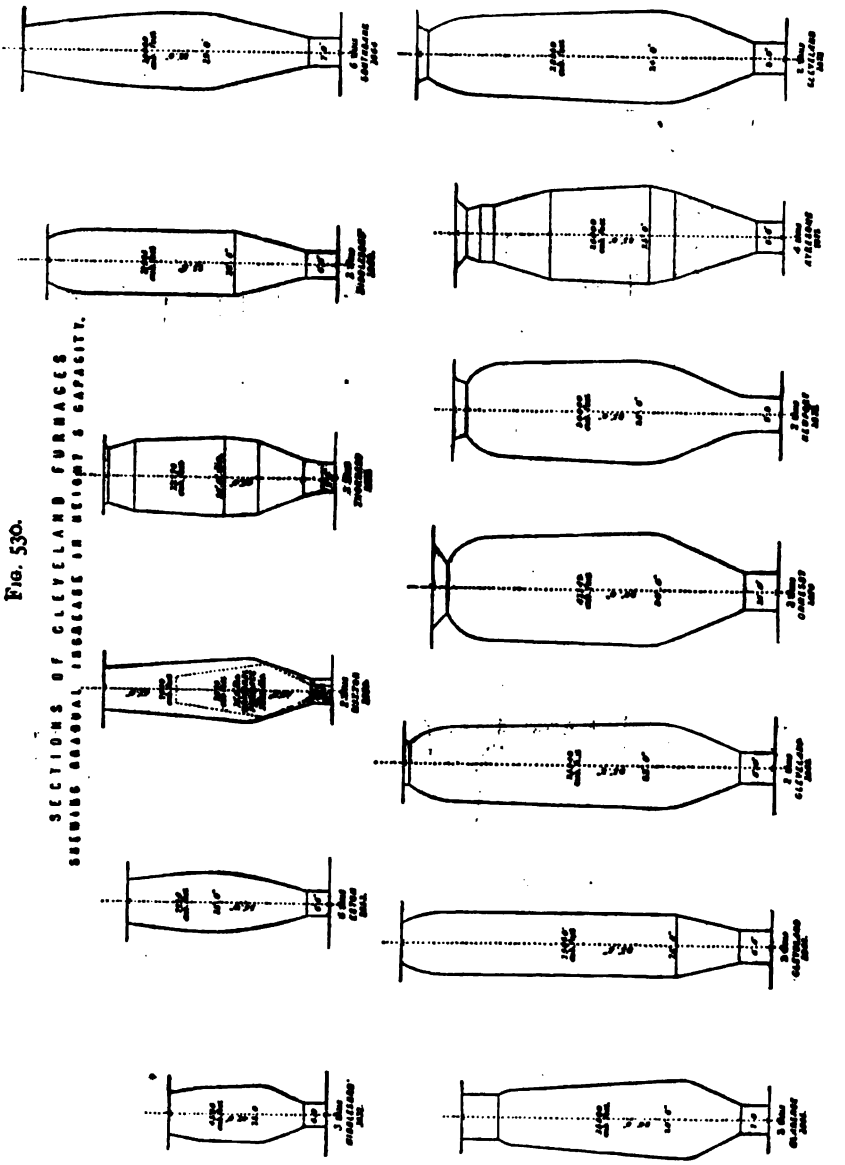


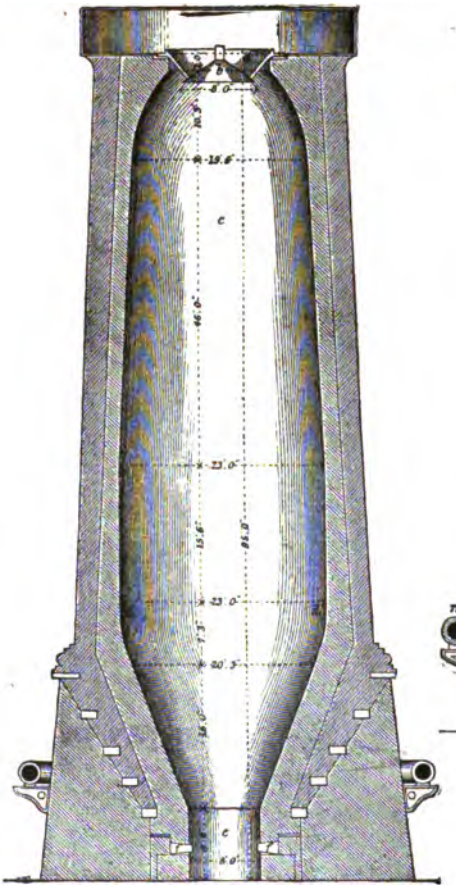
Fig. 530.

SECTIONS OF CLEVELAND FURNACES SHEWING GRADUAL INCREASE IN HEIGHT & CAPACITY.

In working the blast furnace, the materials, consisting of iron ore, fuel, and fluxes, are charged into it at the top or tunnel head, generally through a cup and cone arrangement, which is used to close the furnace for the withdrawal of the gases without igniting them. The hot blast enters by the

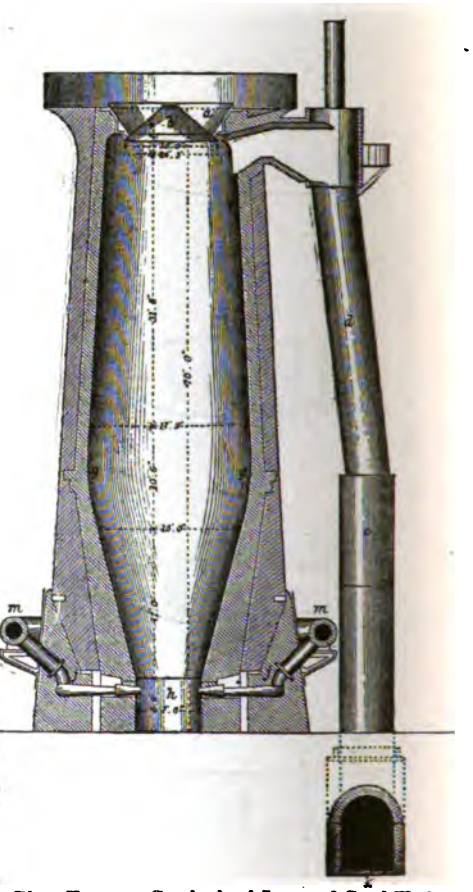
tuyères which are connected with the pipes leading from the hot blast stoves, and a zone of very intense temperature is created in the region of the tuyères. The iron, which has been reduced from the oxide to the metallic state, in its passage with the charge down through the furnace where it has been exposed to a reducing atmosphere of carbonic oxide, is melted in this white hot zone, and drops down to the hearth, collecting in the crucible, or portion of the furnace just under the tuyères, from which it is periodically tapped and run out. The carbonic anhydride formed by the combustion of

Fig. 531.



Blast Furnace, Eston Ironworks.

Fig. 532.



Blast Furnace, Cumberland Iron and Steel Works.

the coke with the hot air of the tuyères in passing upwards, meets with solid carbon with which it combines and is thus reduced to the state of monoxide (carbonic oxide); this, to a greater or less extent, becomes carbonic acid once more by combining with the oxygen of the iron ore in the upper part of the furnace.

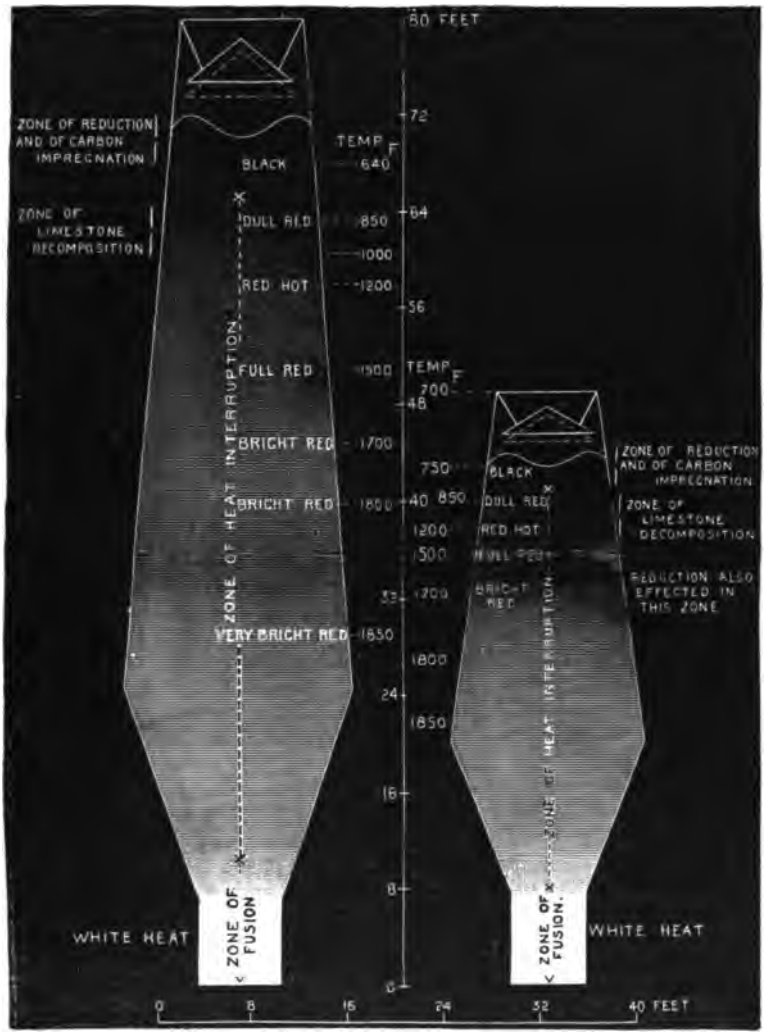
The hydrogen present in the furnace also acts as a reducing agent to some extent, but the carbonic oxide is not only the most abundant, but also the most active agent, so that Sir I. Lowthian Bell * has shown that the ratio of

* "Chemical Phenomena of Iron Smelting;" also "Studies of Blast Furnace Phenomena," by M. L. Grüner.

$\frac{CO_2}{CO}$ found in the escaping gases is the index of the working of the furnace.

Sir I. Lowthian Bell says,* "The intensely heated gases which ascend from the hearth, having to perform the duty of reducing the ore as well as to heat the materials, the point which has to be kept in view in the construction of the blast furnace is, that its capacity should suffice for the

FIG. 533.



heated gases to be retained among the solids long enough to communicate to the latter as much of their sensible heat as is possible, and to become as completely saturated with oxygen as the nature of the chemical action will permit. These two objects seem to be attained in the Cleveland district, when the furnace has a height of 80 feet, with an interior capacity of about 12,000 cubic feet. These dimensions enable the gases to be cooled down to

* "Principles of the Manufacture of Iron and Steel."

such a point, and to be so saturated with carbonic acid as to retain little or no further power of reducing the ironstone of the country. The correctness of these views has been made apparent by the fact that furnaces, mentioned as having been constructed upwards of 103 feet high, and others nearly as lofty, with a capacity of 40,000 cubic feet, have failed to show any marked advantage, so far as economy of fuel is concerned, over that which has been frequently obtained in those of more moderate dimensions."

The two illustrations, Fig. 533, are given by this author to afford a general idea of the temperature of the materials filling two furnaces, one 80 feet high with boshes of 20 feet, and having a capacity of 15,400 cubic feet, and the other of 47 feet in height with boshes of 16 feet and a capacity of 6000 cubic feet.

The temperatures marked on the figures were roughly ascertained by drilling holes in the sides of the furnaces at various heights, but these are considered by Sir I. L. Bell himself to be merely comparative from the fact that the contents of the furnaces may be hotter nearer the centre.

He remarks on these illustrations: "The advantages possessed by the larger furnace are, firstly, that the gases pass away cooled, as far as it is practicable to effect this; and, secondly, that the deoxidation of the oxide of iron is performed in a portion of the furnace where the temperature is so low as to avoid as much as possible the carbon acting on the carbonic acid, generated by the act of reduction. The comparative magnitude of this zone of moderate temperature in each furnace can easily be appreciated by an inspection of the two sketches. In the larger one the contents do not exhibit a dull red until a depth of 16 or 17 feet is reached; whereas in the other this temperature manifests itself at a depth of about 9 or 10 feet. In each case the distance is reckoned from the charging-plates.

"It might be supposed, at first sight, that the conditions of the two furnaces could be brought into harmony by diminishing the rate of driving in the lesser. The increased period of time, however, during which the ore would then be exposed to the action of the heated gases only brings the hotter zone nearer the top of the furnace, and an actual trial of slower driving extended over some time, induced me to think that there was no gain to be expected from a change of that kind."

Sir I. L. Bell's description of the arrangement of temperatures is, however, accepted by Mr. Charles Cochrane* and other authorities as showing the order, but not the proper extent of some of them, as, for instance, the cool region at the top.

Cupolas.—Cupola furnaces† used in foundries for melting iron for the production of castings are also worked with solid fuel, usually coke, in contact with the charge of iron, the furnace being worked by a blast, usually of cold air. Similar furnaces are used in some copper smelting operations.

A very interesting and useful *résumé* of the progress in cupola furnace design has recently been presented to the Cleveland Institute of Engineers by Mr. Charles Hornung, of Middlesbrough, who has permitted us to make the following quotations from his paper:—

"Originally cupolas were square, round, or oval in section, and provided with a single tuyere only, the lining being composed of a refractory sand rammed up around a metal core to the desired shape; but this lining was found to wear away very rapidly, and required frequent repairs, hence it came about that the sand was gradually replaced by fire-brick. The height of these cupolas was usually only about 6 feet, and the consumption of fuel

* See "Jour. Iron and Steel Inst." No. 1, 1885; see also Bagnall on the Development of Heat in Blast Furnaces: "Jour. Iron and Steel Inst.," ii. 1871, p. 245.

† Refer to "Jour. Iron and Steel Inst.," vol. i. 1884, p. 197, ii. 1882, pp. 741, 780, 783; "Scientific American," Nov. 1884.

reached as much as 10 cwts. per ton of metal melted. The capacity of these cupolas was found inadequate for all but the lightest work, so, in order to collect a larger quantity of iron in the crucible, or lower part of the furnace, five or six tuyeres were placed on either side of the cupola, one above the other, about 10 inches apart, and connected outside by vertical pipes, only one tuyere being used at a time. When the blast was turned on, all the tuyere holes, excepting the lowest one, were closed; then, as the melted metal in the crucible rose up to the level of this bottom tuyere, it was stopped up and the next above it opened; and so on, in rotation, until the top tuyere was open and those beneath it all stopped up, after which the metal was tapped out in the ordinary way.

"About the year 1860, Mr. Ireland patented a cupola (Fig. 534), the lining of which was made smaller in diameter at the tuyeres. The supe-

FIG. 534.

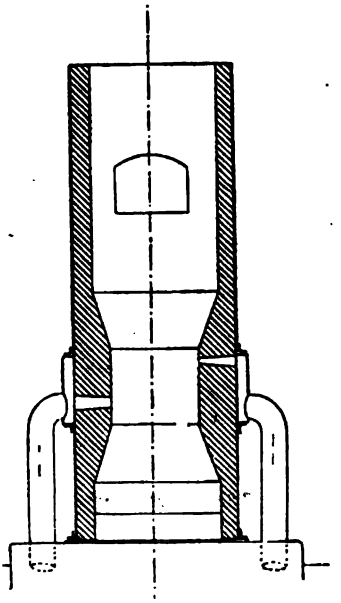
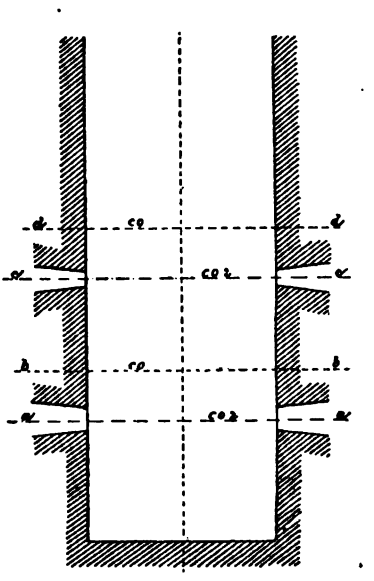


FIG. 535.



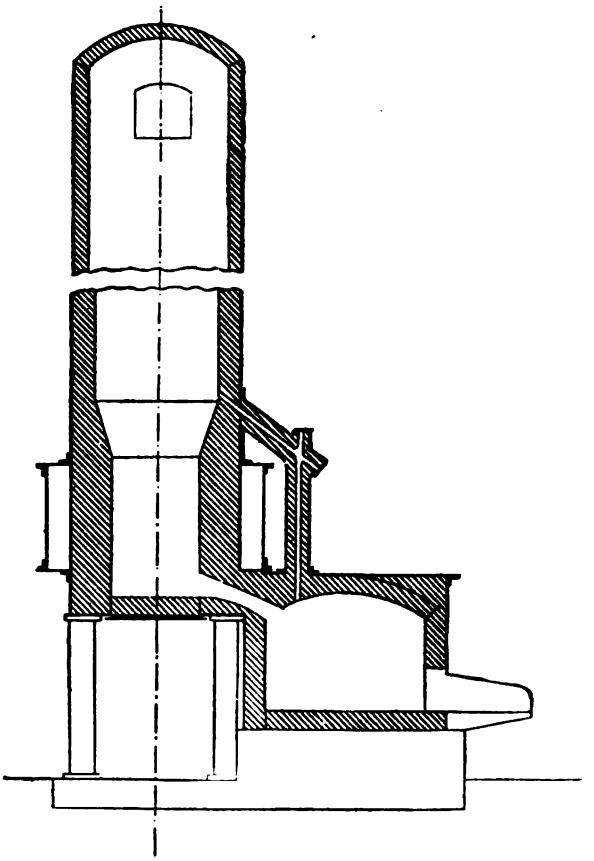
riority of the working of this furnace over those generally in use at that time was due to the more careful system of charging adopted and to the better proportioning of the internal shape. The method of working as described by Ireland was as follows:—After lighting up and heating the cupola by means of a small fire kindled in the usual way, 7 cwts. of coke were charged, and on the top of this 1 ton of pig iron, broken up into pieces about 10 inches long, next 2 cwts. of coke and 1 ton of iron, the subsequent charges being about 1½ cwt. of coke and 1 ton of pig, according to the quantity of metal required. The cupola contained, when full up to charging level, about 6 tons of pig iron and 15 cwts. of coke, or 12½ per cent. of coke.

"Owing to the gradual narrowing towards the tuyeres of the internal diameter of the Ireland furnace, the charges obtained a regular descent, and, owing to the combustion being concentrated in a smaller space for the same amount of coke burnt, the temperature immediately in front of the tuyeres was much higher than in the ordinary cupola with parallel sides. In order to allow of collecting and keeping a good supply of melted metal, Ireland

increased the diameter of the lower portion of his cupola, generally termed the crucible or well. The tuyeres were placed in two horizontal rows, sixteen tuyeres about 3 inches diameter in the upper, and four tuyeres 8 inches diameter in the lower row. This does not seem to have effected much economy, but only to have increased the melting zone, as may be seen by considering Fig. 535, where *a a* represents the centre line of the row of lower tuyeres, and *c c* the row of upper and smaller ones; in both cases, carbonic oxide is produced just above the tuyeres, at *b b* and *a a* respectively, in consequence of the upper tuyeres *c c* being introduced at a point in the furnace where the coke is of such a high temperature that it ignites on the further combustion of carbonic oxide and oxygen.

"The Stewart cupola (Fig. 536), commonly known as Stewart's rapid cupola, is provided with three rows of tuyeres close together, which produce

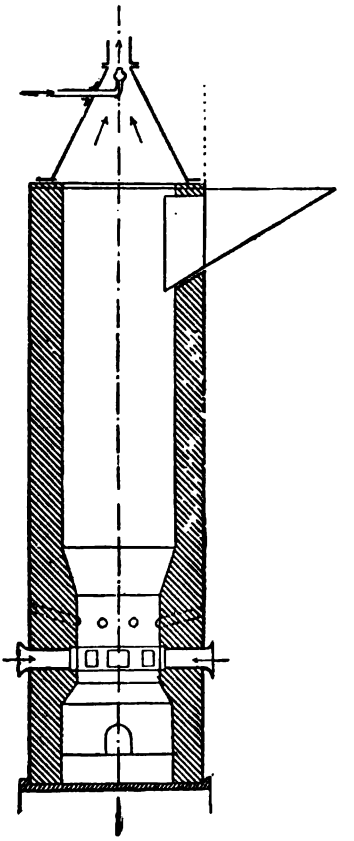
Fig. 536.



an effect similar to that of Ireland's arrangement; the melting zone is also increased, and the metal has to pass through a greater space, where it is subjected to the oxidizing influences of the incoming blast. To some extent this oxidation of the molten metal is prevented by raising the hearth of the furnace up to within a few inches of the tuyeres, and having, in place of the well or crucible for the melted metal, a separate receiver connected with the cupola by means of a brick-lined spout from its hearth level. This receiver

is entirely lined and roofed with fire-brick, and is provided with the necessary tapping and slagging holes. Leading off from the roof of the receiver to about the centre of the charge in the cupola is a pipe, lined with fire-clay to about 2 inches diameter; this pipe carries away the heated gases from the surface of the molten metal and delivers them into the centre of the descending charge, which is thereby partially heated before arriving at the melting zone. Owing to the depth from the hearth level being so very much smaller than in other cupolas, the coke for lighting up is considerably reduced. The difficulty of Stewart's arrangement, however, seems to be in the receiver itself; this is apt to become clogged up with slag, and has to be cleaned out entirely every night, which is a great inconvenience in the case of working for two or three days with the same furnace.

FIG. 537.



"Heaton patented a cupola worked by means of the draught caused only by the height of the chimney and the ascensional power of hot air, instead of forced blast, but this method was slow and entirely unsuited for intermittent working.

"Woodward's cupola* (Fig. 537) was worked by means of an induced current created by a steam jet blowing up the chimney. There were two rows of rectangular tuyeres, or, rather, holes, for the admission of the air, usually eight in the upper and four in the lower range. The jet was a simple contracted nozzle, fixed in the centre at the bottom of the chimney, about 4 feet above the charging level. The steam for creating the draught was said not to be greater than would be required for driving an engine and fan. Woodward claimed that the coke consumption in one of his cupolas for ordinary work was about 10 per cent. of the metal charged, including 'lighting up.' The charge was introduced by means of a hopper at the side of the furnace. The first cost of such a cupola and plant was much reduced owing to the absence of an engine and fan, but it is doubtful if the actual results were as good as those given in some accounts; at all events, this system of working seems never to have come into general use.

"Some of these difficulties appear to have been overcome in the Herbertz cupola (Fig. 538), which in the place of tuyeres is provided with an annular opening, so constructed that it can be varied in height as required according to the working of the furnace. Steam consumption is given as about 203 lbs. per hour, with a jet $\frac{3}{8}$ inch diameter, and a comparison of this with a cupola of similar dimensions worked with forced blast from a 3 h.-p. Root's blower, which required about 198 lbs. of steam per hour, shows there is no economy obtained by means of the jet. The consumption of coke in two experiments mentioned in *Stahl und Eisen*, in June 1886, was 5 per cent. and 10.2 per cent. for melting only, and 9.9 per cent. and 12.7 per cent. total, including

* See F. Kohn's "Iron and Steel Manufacture." (London: W. Mackenzie.)

lighting up, or, taking the mean, it equalled over 2 cwts. of coke per ton of metal melted.

"Analyses of the gases at the top of a Herbertz cupola in the experiments above referred to, show carbonic acid 10.7 to 11.5 per cent., carbonic oxide 0 to 3.4 per cent., and oxygen 6.7 to 8.2 per cent., or an average of 7.5 per cent. of oxygen. This 7.5 per cent. of oxygen is in excess of that required for combustion, and robs the furnace of considerably more heat than would the escape at the top of the charge of 2.55 to 11.73 of carbonic oxide. The excess of oxygen in an ordinary cupola causes extensive decarburization of the metal, but in the Herbertz system its action is not so injurious, owing to the melting zone being smaller, and the iron being consequently exposed to the action of the gases for a shorter time.

FIG. 538.

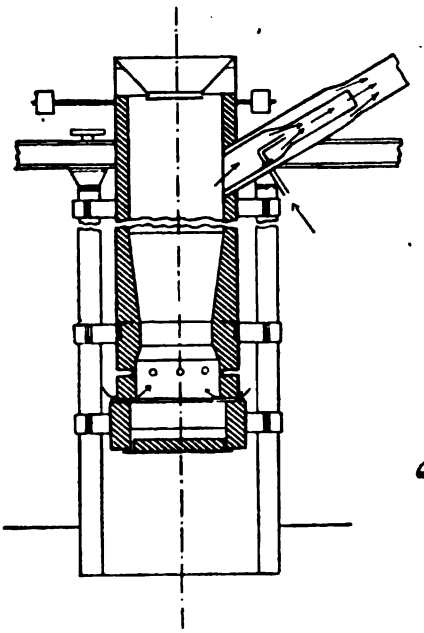
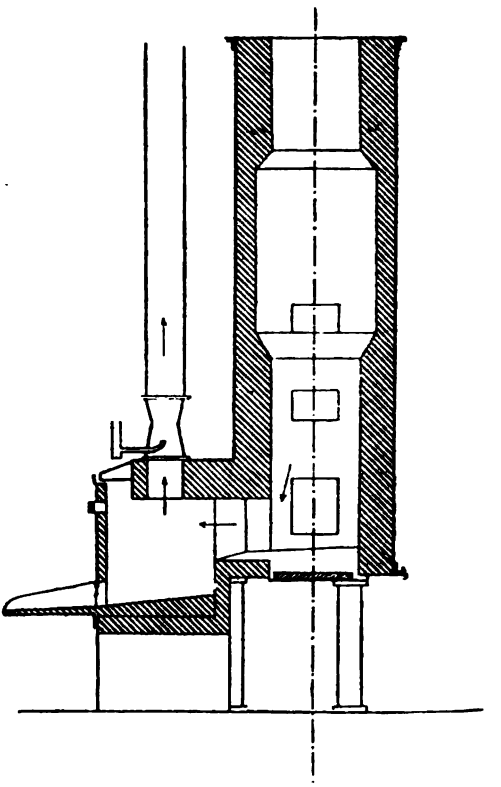


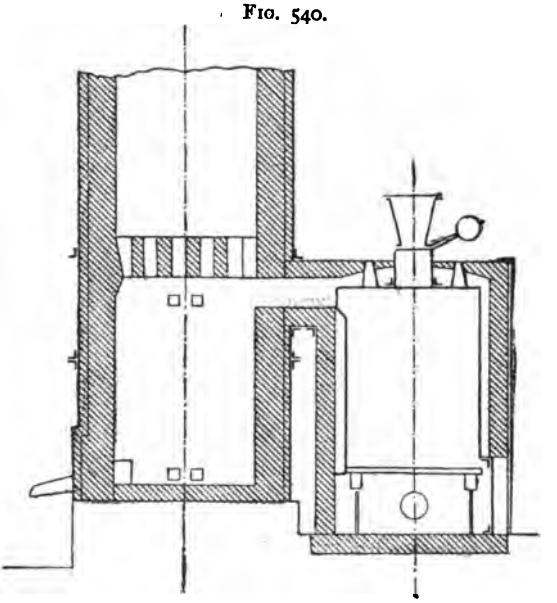
FIG. 539.



"Krigar's cupola (Fig. 539), with a receiver and induced current, was arranged so that the air, instead of passing up the shaft of the cupola, entered at two or three different levels below the top of the charge, and was drawn *downwards* towards the melting zone by means of a steam jet placed in a chimney on the roof of the receiver. The gases helped to keep up the heat of the metal collected in the receiver, but the charge arrived at the melting zone almost cold after the passage through it of the cold air. The consumption of coke averaged about 13 per cent. as compared with the melted metal. The waste of iron was reduced by this system, because the molten metal was not subjected to an oxidizing atmosphere of ascending air.

"Dufréné patented an arrangement (Fig. 540) of a gas producer connected direct to an ordinary cupola. The air for the combustion of the

FIG. 540.



producer gas circulated round the sides of the producer, and so became heated previous to uniting with the gas inside the cupola. The gas was admitted at the top of the crucible portion of the furnace, about the height at which the tuyeres are usually placed. Just above this gas port was a grating, composed of refractory material, on which the pig iron to be melted was placed. [Other plans of gas cupolas will be found in the section on gas furnaces.]

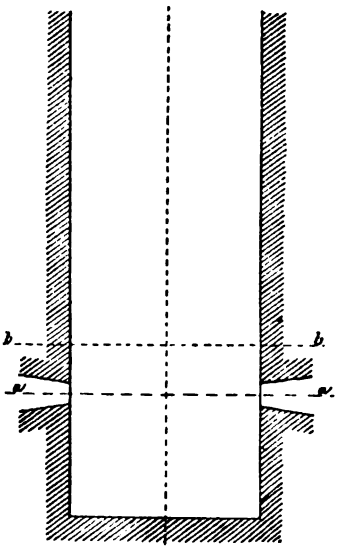
"An arrangement of Siemens regenerators working in connection with a cupola was brought out in 1884, by Mr. Bramall, of Sheffield. Each of the regenerators was alternately heated by means of the waste gases from the cupola, previous to the introduction of the producer gas. This appears, however, to be based on a wrong system, for in order to heat the regenerators, the waste gases must be at a relatively high temperature, which would only be the case when the cupola was working badly.

"Another cupola working on a similar system was brought out by Mr. Henry Krigar, of Hanover. It consisted of two distinct shafts and a receiver. The pig iron and scrap were charged into the shaft most remote from the receiver, which shaft was left open at the top, the fuel being charged into the second shaft, which was closed at the top. Blast, admitted into the stack of fuel only, passed through the lower portion of the coke and ascended the shaft containing the pig iron; by this means, the melted metal came in contact with the coke previous to passing into the receiver.

"At one time the utilization of waste heat at the top of the charge was considered to be one of the most important points in the economical working of a cupola. This was effected in various ways. First, the blast was passed through a series of pipes placed in the chimney of the cupola, but this arrangement was costly compared with the results obtained. Then, the waste heat was made to traverse a chamber in which the iron and coke was stacked previous to being charged into the furnace; but very little, if any,

economy was derived. At Woolwich, a cupola was erected having a blast box extending over its entire height from the tapping-hole to the charging level; the blast entered at the top and was raised in temperature by the heat radiating from the walls of the furnace. Attempts have also been made to utilize the waste heat for raising the steam necessary for driving the fans, &c. But none of these ideas has proved successful, owing to the irregular and intermittent working of foundry cupolas.

FIG. 541.



"In the different systems already mentioned, with the exception of Ireland's, this fundamental fact seems to have been entirely disregarded—namely, that carbonic acid coming in contact with red-hot fuel combines with a certain quantity of carbon to form carbonic oxide, thereby robbing the coke of some of its carbon; the complete conversion of the coke into carbonic acid seems to have been only a secondary consideration. In an ordinary cupola, with one row of tuyeres, usually placed about 2 feet 6 inches above the metal in the crucible, the carbonic oxide formed by the combustion of the coke in front of the tuyeres *a a* (Fig. 541), comes in contact just above, at *b b*, with a layer of incandescent fuel, and a considerable portion is converted into carbonic oxide, which, having no oxygen to combine with, rises to the surface of the charge, and, meeting with the oxygen of the atmosphere, burns, if hot enough, with its characteristic blue flame, or, if too cold to ignite, passes away invisibly.

"Voisin (see Fig. 542) employed two rows of tuyeres, the upper row being placed at the level at which the formation of carbonic oxide was greatest, this level being ascertained by taking the temperatures at different heights. Undoubtedly he was on the right road, and deserves all the credit due to a pioneer; but his efforts met with only partial success; and this for a very simple reason—namely, that the combustion of the carbonic oxide at once ignited the hot coke, and, in fact, caused an upper zone of fusion, above which the original process was repeated by the absorption by the carbonic acid of an equivalent of carbon from the glowing fuel, and the consequent reduction to carbonic oxide and loss of heat.

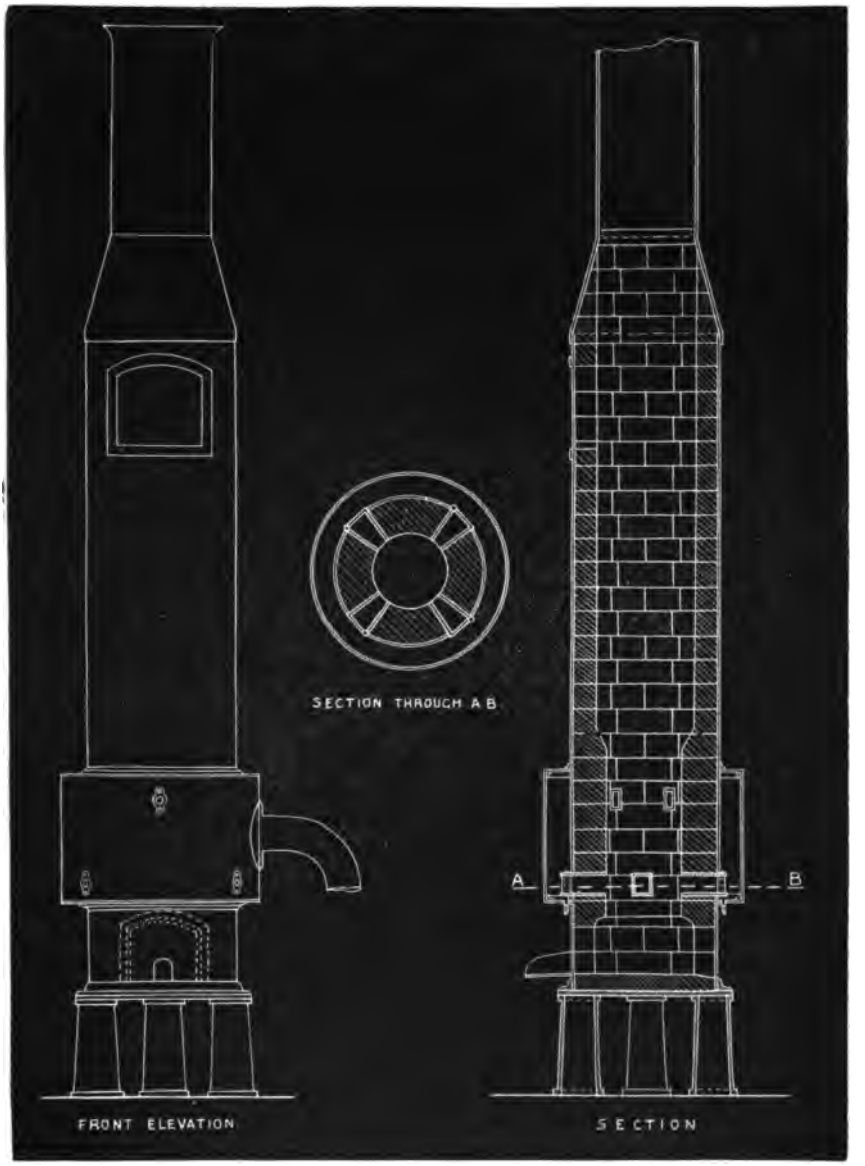
"Since then several attempts have been made to utilize the waste gas more completely; but they have invariably stumbled at the difficulty of burning the gas without attacking the solid fuel. This difficulty, however, at last appears to have been overcome; Arthur Greiner and Thuisco Erpf, as the result of some experimenting, having adopted the plan of arranging a number of small blast inlets over an extended upper zone of the body of the cupola, through which, by careful manipulation of the blast, they have managed to convert practically the whole of the carbonic oxide into carbonic acid below the surface of the charge (see Fig. 543).

"A very thorough exposition of Greiner and Erpf's invention appeared in the Engineer of December 9, from which the following is quoted:—

"Messrs. Greiner and Erpf, in their endeavour to solve the problem of the utilization of the inevitable carbonic oxide, after careful study of the phenomena attending combustion in cupolas, have made an entirely new departure. They perceived that, to effect the required result, the combustion

of the carbonic oxide must be commenced at a point so far above the fusion zone that the descending coke has not attained the temperature necessary for ignition, while the ascending combustible gas is still hot enough to ignite on contact with air. Furthermore, the burning of the gas must not take

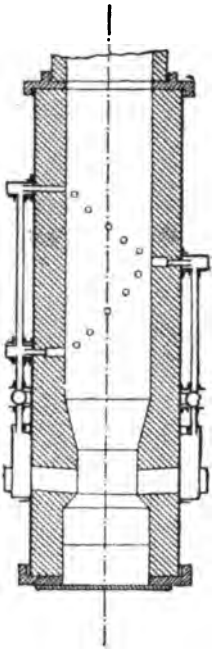
FIG. 542.



place in one horizontal plane, but must be distributed through some depth of the charge, otherwise the concentration of heat would cause ignition of the coke, and consequent loss. The drawing (Fig. 543) shows a section of a cupola on this system, the supplementary blast being introduced above

the point where the fuel has not quite attained the temperature necessary for ignition. The carbonic oxide is thus burnt to carbonic acid, and the descending mass of coke and metal receives the full benefit of the combustion temperature; while, owing to the method of distributing and regulating the supplementary blast, the heat at no point is great enough to fire the coke, or to permit of any reaction between it and the carbonic acid. The upper blast is introduced through a number of small tuyeres placed around the cupola in such a way as to secure a thorough distribution of the air currents.'

Fig. 543.



"The analyses made by Messrs. Pattinson and Stead show that this invention effects in a very complete manner the utilization of the carbonic oxide. The samples were taken from the waste gases just above the charge, near the inside lining of two cupolas at the works of the Anderson Foundry Company. One of the cupolas was of the ordinary first-class foundry pattern; the other was a similar cupola altered to Greiner and Erpf's system.

	Ordinary Cupola.		Greiner and Erpf's Cupola.
Nitrogen	75.50 %	...	79.92 %
Carbonic oxide . . .	11.50	...	1.25
Carbonic acid . . .	12.50	...	18.75
Hydrogen	0.50	...	0.08
	100.00	...	100.00

"Messrs. Pattinson and Stead, in a note on these analyses, say:—'The results show that the heat developed in the cupola, where the gas produced at the main tuyeres is burnt by air injected above, is about 30 per cent. greater than is developed in the ordinary cupola. For many reasons the practical saving of coke in large cupolas will not reach that point, but the results prove beyond doubt that the system is a correct one, and must produce a considerable economy of fuel.'

"From these analyses we find that in the ordinary cupola 9,438.2 heat units are developed per lb. of carbon. Taking the melting-point of cast iron as 2780° F., its specific heat as 0.13, and 40° F. as the average temperature of a pig of metal, coke containing 89 per cent. carbon, we get—

$$2780 - 40 = \frac{2740 \times 0.13 \times 2240}{9438.2 \times 0.89} = 95.00 \text{ lbs.}$$

the amount of coke required to melt 1 ton of cast iron.

"To this must be added the following:—

Melting slag and burning limestone . .	} =	2.87 lbs.
Carbon burning to CO		
20 lbs. slag per ton of metal		
Carried off by waste gases at temp. 770° F. . .	=	9.90 „
6 % for radiation	=	5.70 „
Total coke per ton of metal melted . . .	=	113.47 „

"In a similar manner, from the analysis of the waste gas from Greiner and Erpf's patent cupola, we find 13,465 heat units developed per lb. of carbon, and using the same calculations we get—

$$2780 - 40 = \frac{2740 \times 0.13 \times 2240}{13465 \times 0\,89} = 66.60 \text{ lbs. coke;}$$

adding the following:—

Melting slag and burning limestone . .		
Carbon burning to CO_2	=	1.90 lbs.
20 lbs. slag per ton of metal		
Carried off by waste gas at 770° F. . . .	=	9.90 „
6 °/₀ for radiation	=	4.00 „
Total coke per ton of metal melted . . .	=	82.40 „

or a reduction in coke consumption of about 27 per cent., as compared with the ordinary cupola."

Metallurgical and Chemical Furnaces.—Richardson's furnace,

Fig. 544.

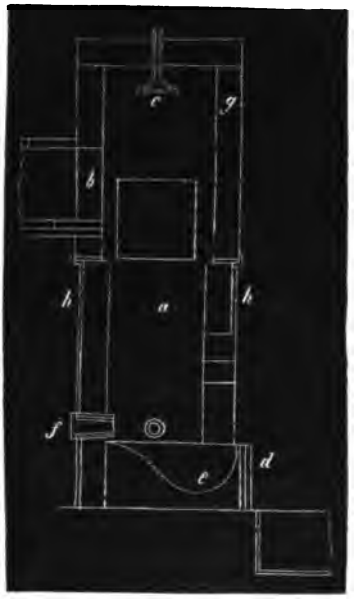
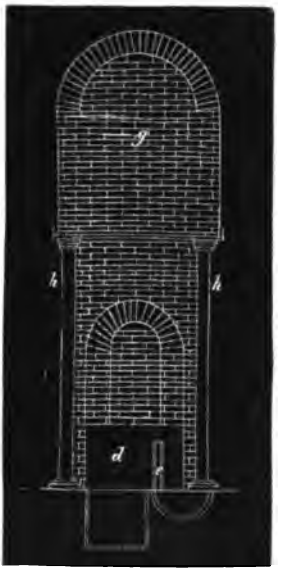


Fig. 545.



Figs. 544, 545, and 546, for treating silver residuums from zinc-ores, &c. &c., furnishes another illustration of the application of the blast.

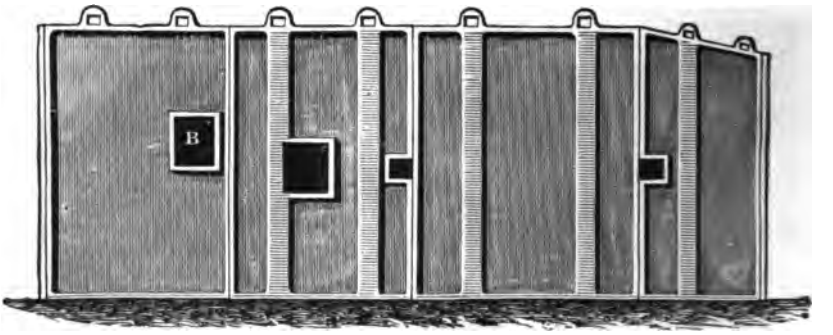
Fig. 546.

a is the body of the furnace, formed of single brick, and the bottom of clay and finely ground coke, well beaten down, and cut into the form shown in Fig. 544. The materials are thrown into the furnace by the charging door *b*, and a fine spray of water made to play upon their surface from a rose situated at *c*. The front of the furnace is supported by a metal casting *d*, over which the slag flows either into water or into metal tubs. When the silver-lead has accumulated in sufficient quantity in the hearth, it is tapped into a pot at the point *e*. The furnace may be worked by means of a blast thrown into the furnace by the tuyeres *fff*, or by increasing the number of these openings to five or six, and connecting the furnace with a tall chimney, when the natural draught will be sufficient. The upper portion of the furnace *g*

is supported on four metal pillars and binders, *h h h h*, which remain untouched on renewing the lower part of the furnace after being worked out.

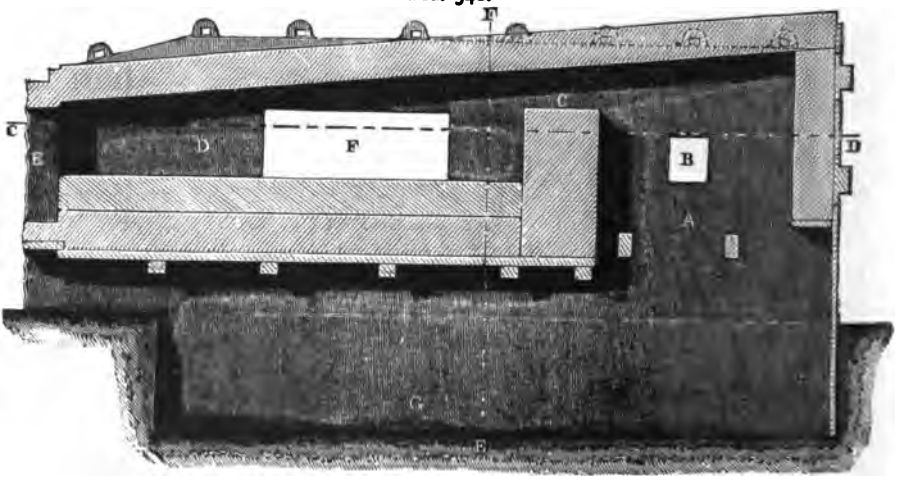
Furnaces in which the flame of the fuel alone is employed, are frequently called reverberatory furnaces. Where solid fuel is used it is burnt upon a grate, and the flame is drawn by a powerful chimney draught over the substances to be heated, which are inclosed by a more or less elevated arch of brickwork. These furnaces are frequently constructed with the bed in two portions at different levels—on one of which the substance is partly heated or prepared while the other serves for the final heating or "furnacing." In some instances the higher part is called the "garret bed" and the

FIG. 547.



lower the "working bed." The charge in many instances is first introduced at the higher level, which is further removed from the fire, and subsequently raked down on to the lower level, where it is exposed to the full heat of the flame; in some processes, however, the opposite course of

FIG. 548.

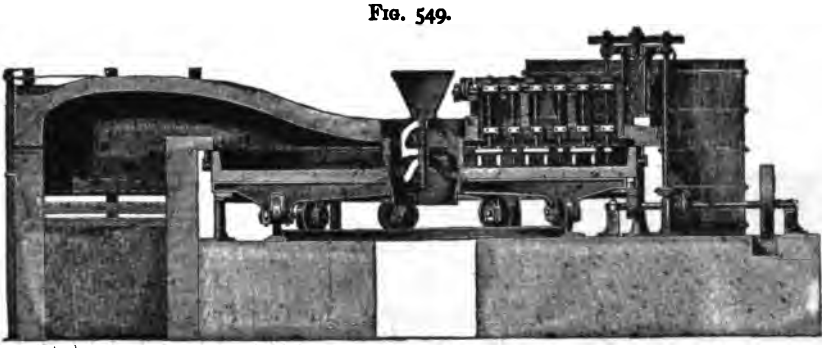


procedure is necessary. Furnaces of this description are employed in the manufacture of carbonate of soda. Figs. 547 and 548 illustrate an ordinary reverberatory furnace with single bed, Fig. 547 being an elevation, and Fig. 548, a longitudinal section of the furnace.

Amongst the furnaces used in chemical manufactures the mechanical furnaces of Mr. Mactear and of Messrs. Jones and Walsh have occupied an important position.

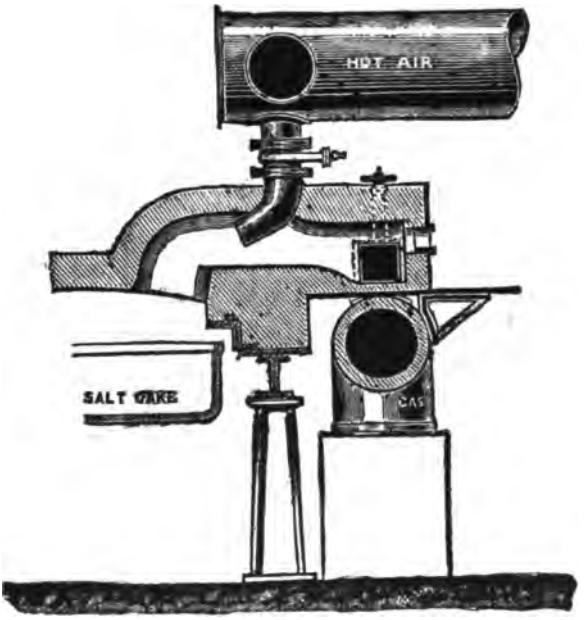
The Mactear furnace* "consists essentially of a revolving bed or pan made of wrought iron lined with firebrick. This pan is carried on a series of girders which radiate from a hollow central piece of cast iron. These

FIG. 549.



girders carry each a bearing wheel, levelled on the tread, and the whole runs on a circular rail or race having its upper surface bevelled to correspond with the wheels, and a flange on the inner side. The race is carried on

FIG. 550.



two massive pieces of brickwork with a roadway between, through which the waggons run when the finished material is being discharged." In the carbonating furnace "the bed has an opening in the centre through which the finished charge is made to fall by being pushed out either by hand or by mechanical arrangements of a very simple kind." Mechanical stirrers are also used and the amount of labour required is therefore very small.

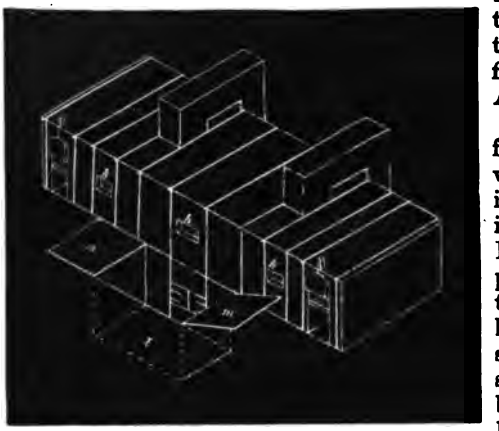
* See J. Mactear, "Jour. Soc. of Arts," Feb. 4, 1881; "Jour. Soc. Chem. Ind.," June 28, 1881.

Fig. 549 shows this furnace as arranged for coal firing. Very good results have however been obtained by the use of producer gas in this furnace.

The furnace of Jones and Walsh* is similar in general design to the Mactear furnace, being also a revolving bed furnace.

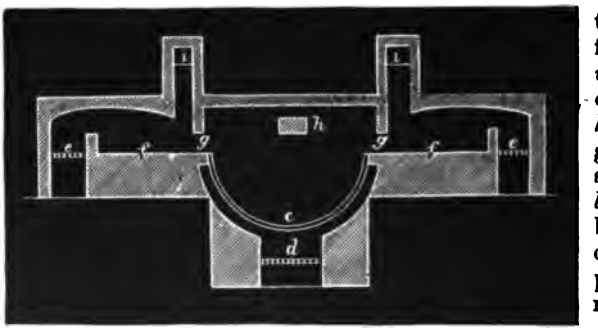
Fig. 550 shows the combustion arrangements in a salt-cake furnace of this kind as worked with gas fuel† at the works of the Newcastle Chemical Company, Gateshead. The air for combustion is heated to 1000° F., and supplied under slight pressure from a fan, and a saving of two shillings per ton of salt treated as compared with coke firing was announced by Mr. Allhusen.

Fig. 551.



The old-fashioned hand furnace for making salt-cake which was displaced by such improvements as the foregoing is pretty well represented in Figs. 551 and 552, which represent the ordinary combination of bottom and surface heat for decomposing common salt. In the section, *c* represents an iron pan, heated from below by a fire *d*, from above by those at *e e*. The drying flats *f f* are separated from the pan by brick partitions, and communicate by means of openings at *g g*, which may be closed with dampers. The bulk of the hydrochloric acid escapes at *h*, when intended for the manufacture of chloride of lime, and what is retained by the partially manufactured sulphate at *i i*. The working-doors are shown at *k k k*; the underground recess for stoking the fire by l_1 which is covered by trap doors *m m* during the decomposition of the common salt.

Fig. 552.



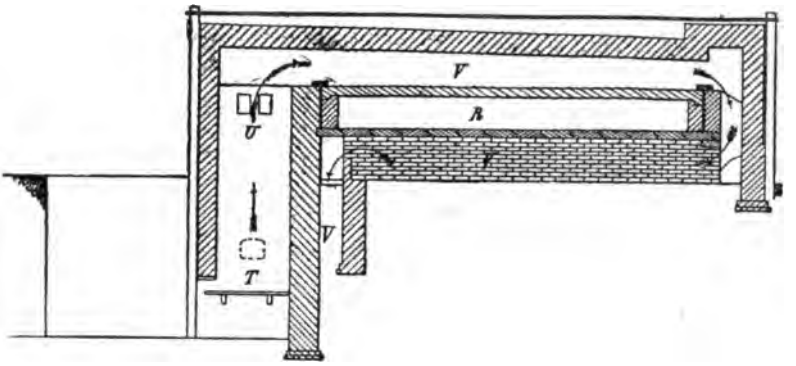
Further improvements in such chemical furnaces have been introduced at the works of Messrs. Gaskell, Deacon & Co., Widnes, and of Messrs. Gamble at St. Helens, both of whom introduced what has been called a "plus-pressure" furnace intended to work certain portions of the manufacture of salt-cake in closed muffles.

Figs. 553, 554, and 555 illustrate the "plus-pressure" furnace, Fig. 553 being a longitudinal section, Fig. 554 a transverse section through the muffle and pot, and Fig. 555 a plan in section showing the various heating flues. In all the figures, *R* is the muffle or close roaster, *S* is the pot, *T* is the

* "Jour. Soc. Chem. Ind.," June 28 and 29, 1881, pp. 33, 34.
† See A. Wilson, "Jour. Soc. Chem. Ind.," Nov. 1883.

grate, *U* the chimney or column of hot air causing the draught or propelling power of the furnace, *V V* are the smoke flues, *W* is the acid gas outlet,

Fig. 553.



X a bye-flue for conveying waste heat to the ordinary chimney when the heat is not wanted under the pot, *Y Y* are openings communicating with the air, and *Z* the ordinary chimney smoke flue.

Fig. 554.

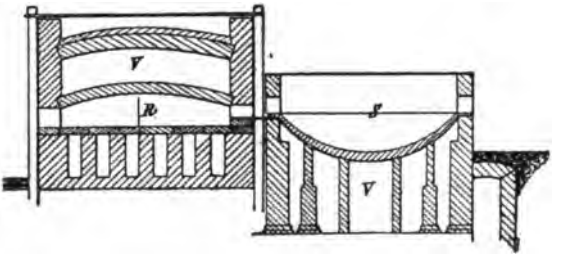
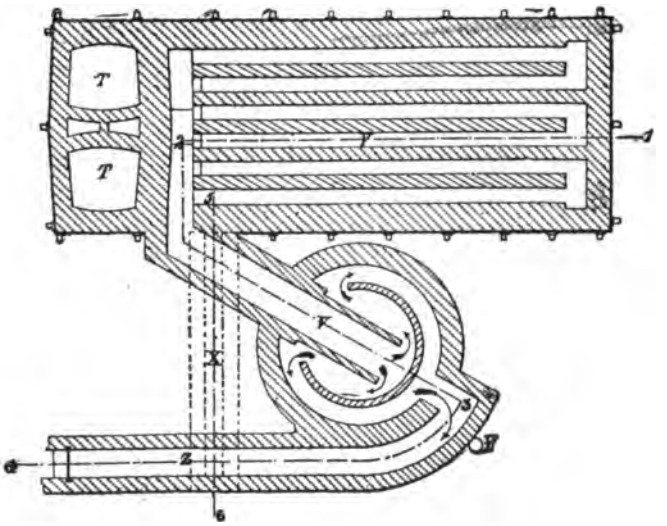


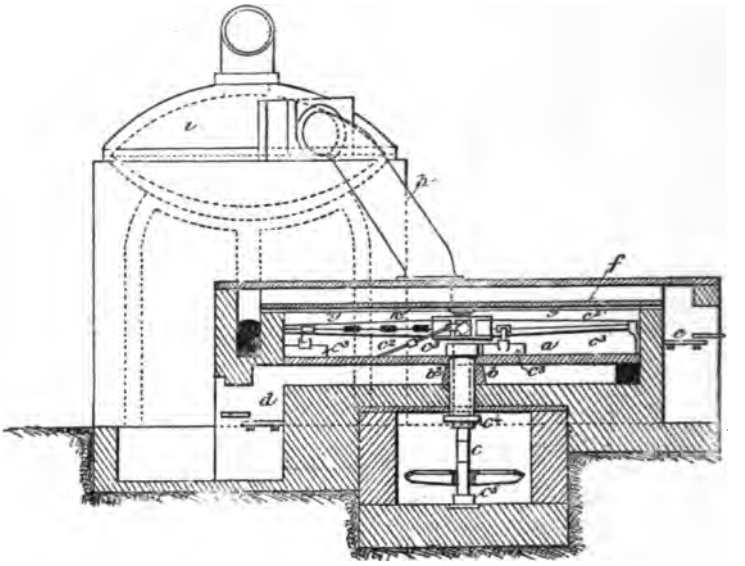
Fig. 555.



The most recent form of the salt-cake furnace is called the St. Bede chemical furnace, from its having been worked out at the St. Bede Chemical Works by Mr. T. Larkin. It is a combination of the old pan and roaster with closed muffles and mechanical stirring, and is said* to possess many advantages over other forms.

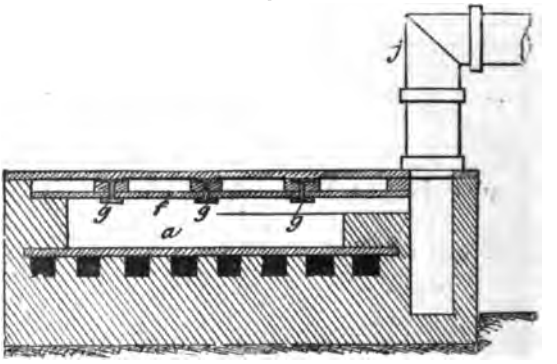
Figs. 556, 557, and 558 illustrate this furnace, Figs. 556 and 557 being sections at right angles to each other and Fig. 558 a plan of the furnace.

Fig. 556.



The bed *a* is made of fireclay quarls or metal plates, having a central opening for the shaft *c* of the mechanical stirrer which is protected by a tube or casing *b*. There are several small "lower" and "higher" fireplaces,

Fig. 557.



d, being one of the lower and *e* one of the higher, arranged at opposite ends of the furnace. The heat from *d* passes under *a*, and is conducted either by "flash flues" or by return flues into the main flue.

The heated gases from *e* are directed over the covers *f* of the furnace by means of flues until they reach the opposite end of the furnace, where they

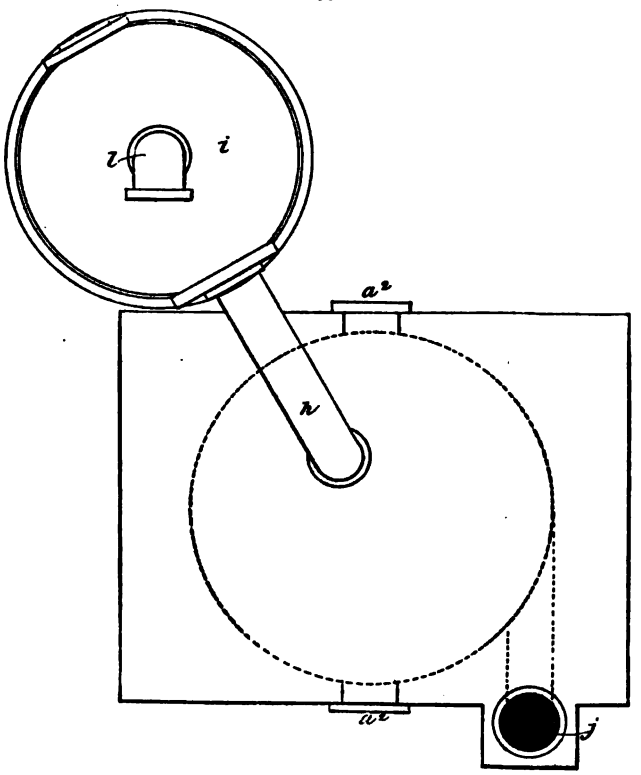
* See "Jour. Soc. Chem. Ind.," May 29, 1885, pp. 316–318.

pass into the main flue or they may be brought down and under the bed by return flues and thence into the main flue.

The cover or roof *f* is sometimes carried by the lower flanges of girders as shown at *g*. In this construction of furnace, the box chamber or receptacle bounded at the bottom side by the bed *a*, and on the top side by the cover *f*, has no direct communication with any of the flues which lead from any of the fire-places.

This closed chamber has several doors, as at a^2, of suitable dimensions for withdrawing the finished charges. A pipe or channel *h* serves for

FIG. 558.



charging the furnace from the decomposing pan *i*, which is heated by waste heat from the main flues. *l* is the outlet for gas from the pan, and *j* that from the closed muffle or roaster. The stirring machinery consists of arms c^3, carried by the vertical revolving shaft *c*, and having stirrers or scrapers c^5 hung on them in suitable positions for stirring or agitating the materials on the bed of the furnace.

The shaft is steadied at the top end by a bracket *k* fixed on one of the girders *g*, and the bottom end is supported on the step c^4. Spur or bevel gearing is used for revolving the shaft and stirrers.

In reverberatory furnaces used for high temperature operations and worked by chimney draught, round coal is the fuel used. For the operation of puddling iron about 24 cwts. of coal are required per ton of puddled bar, the iron being treated in charges of 4 to 5 cwts. each, in single furnaces. In double furnaces, the charges are heavier and the proportion of coal used is less.

In some reverberatory furnaces, slack or dross is used for fuel, 30 cwts. of slack per ton of puddled iron having been used in Staffordshire. In many ironworks, the use of dross in such furnaces is accompanied by closing the ash-pit and forcing the draught by a steam-jet blower which delivers air and steam under the fire-bars.

In re-heating and forging, these furnaces consume 8 cwts. to 12 cwts. and upwards of good coal per ton of iron. In double furnaces, the quantity of coal used is less, and in general larger charges are more economical than smaller ones.

Sir W. Siemens, speaking in the year 1873,* estimated that metallurgical furnaces in this country consumed about 40,000,000 out of the 120 million tons of coal raised per annum, but showed that this fuel was used in these furnaces in a very wasteful fashion. "Taking the specific heat of iron at 0.114, and its welding temperature at 2900° F.," he said "it would require $0.114 \times 2900 = 331$ heat-units to heat 1 lb. of iron.

"A pound of pure carbon develops 14,500 heat-units, a pound of common coal, say 12,000, and therefore one ton of coal should bring 36 tons of iron up to the welding point. In an ordinary re-heating furnace, a ton of coal heats only $1\frac{2}{3}$ ton of iron, and therefore produces only $\frac{1}{21}$st part of the maximum theoretical effect.

"In melting one ton of steel in pots, $2\frac{1}{2}$ tons of coke are consumed, and taking the melting point of steel at 3600° F. and the specific heat at 0.119, it takes $0.119 \times 3600 = 428$ heat-units to melt a pound of steel, and taking the heat-producing power of common coke also at 12,000 units, one ton of coke ought to be able to melt 28 tons of steel. The Sheffield pot steel melting furnace therefore only utilizes $\frac{1}{70}$th part of the theoretical heat developed in the combustion."

These estimates, however useful in directing attention to the undoubtedly wasteful character of ordinary coal furnaces, are founded on the assumption that all the heat produced by combustion could be applied exclusively to the iron or steel. This, however, is impossible, as the furnace itself must be maintained, in spite of radiation and other sources of loss of heat, at the desired temperature, and draught must be produced; so that, as Professor Osborne Reynolds has shown† is the case in the steam engine, the heat is used partly in doing work and partly in promoting the rate at which the work can be done.

The temperature required for the conversion of cast into malleable iron is very intense, and is obtained by the consumption of a very large amount of fuel in the puddling furnace, where the draught is produced by a chimney not exceeding 35 feet in height. Mr. Prideaux showed, in the Treatise on Fuel before alluded to, that it is a very extravagant application of fuel to employ it for the production of a powerful draught by means of the ordinary chimney, and that much greater heat would be obtained from a small proportion of the fuel now consumed, if it were used to raise steam for driving a fan, by which heated and compressed air could be supplied to the ash-pit. The ash-pit must then, of course, be closed, with the exception of the tuyères for the admission of the blast. An ample supply of hot compressed air to the interior of the furnace would also be very advantageous, in preventing the influx of cold atmospheric air through the working-holes and the crevices of the brick-work, which must, on the present system, tend to lower the temperature very materially. Although this view has been repeatedly pressed since the remarks in Prideaux's treatise appeared, and calculations have proved a saving of at least 25 per cent. of

* "On Fuel," British Association Lecture, 1873.
† "The General Theory of Thermo-dynamics": Lecture, Inst. C.E., 1883-4.

heat by the use of mechanical draught, yet it has not, except in the case of blow-pipe gas furnaces, made much progress. In torpedo launches and some other vessels, forced draught is employed, but from other considerations. On this subject see "Forced Combustion," pp. 384–389.

The following estimate of heat production and utilization in puddling furnaces is due to Mr. D. K. Clark. The total heat of combustion of 1 lb. of coal of average composition is 14,133 British thermal units; the weight of the gaseous products of combustion is 11.94 lbs. and the specific heat of the mixture of gases may be taken at 0.246. To raise these gases 1° F., we require $11.94 \times 0.246 = 2.935$ units; and the temperature of combustion, supposing the initial temperature to be 62° F., is—

$$\frac{14,133}{2.935} = 4,815 + 62° = 4877° \text{ F.}$$

In practice, this temperature is not reached, the surplus air carrying off a large quantity of heat.

Taking this surplus air at 50 per cent. of the theoretical quantity required for combustion, its weight is 5.35 lbs. to be added to the 11.94 lbs. gaseous products of combustion, making in all 17.29 lbs. per lb. of coal consumed. The mean specific heat of this mixture being taken at 0.243, to raise it 1° F., $17.29 \times 0.243 = 4.207$ units are required, and the temperature of combustion is then $\frac{14,133}{4.207} = 3359° + 62° = 3421°$ F. This is 1456° less than the theoretical maximum temperature. The quantity of heat absorbed by the iron in the furnace has been determined by M. Clement to be 504 units per lb. of iron, when cold pig iron is raised to the melting point, which is taken at 2000° F. One ton of iron thus treated therefore absorbs $2240 + 504 = 1,128,960$ units, and the quantity of coal the complete combustion of which (at 14,133 units per lb.) is theoretically equivalent to this quantity of heat is $\frac{1,128,960}{14,133} = 79.9$ lbs. That is to say, that the net quantity of heat absorbed by one ton of melted pig iron is equivalent to the heat of combustion of 80 lbs. of coal.

When the melted iron has been by puddling made into wrought or malleable iron it absorbs a further quantity of heat in consequence of malleable iron having a higher specific heat than cast iron. Taking the temperature at 2900° F., or something in excess of welding heat, and 0.185 as the specific heat, then 1 lb. of puddled iron in the furnace contains 536.5 units, and one ton contains $2240 + 536.5 = 1,201,760$ British units, for the generation of which heat the quantity of coal required is $\frac{1,201,760}{14,133} = 85$ lbs.*

Omitting from the calculation the heat produced by combustion of the carbon contained in the pig iron, and not making any allowance for loss of weight of iron by waste, we may take 18 cwt. or 2016 lbs. per ton as the total quantity of coal used in ordinary double puddling furnaces, and express the efficiency of the furnace in terms of the fuel utilized, as follows:—

$$\frac{85 \times 100}{2016} = 4.21 \text{ per cent.}$$

Assuming that the heat absorbed by the iron in heating, or "re-heating" furnaces, as they are called, is the same as in puddling furnaces, or equivalent to the combustion of 85 lbs. of coal, and taking the total

* The late Mr. W. Gorman estimated that "a ton of iron at the welding point contains only the amount of heat which is due to about 56 lbs. of coal," but he has not stated the basis upon which he calculated this result (see "Proc. Inst. E. and S. in Scotland," 1871).

quantity of coal consumed in these furnaces as 8 cwt. or 896 lbs. per ton of iron, the furnace efficiency is $\frac{85 \times 100}{896} = 9.49$ per cent.

The quantity of heat which is carried off by the waste gases may be thus estimated:—The temperature of 2900° F. has been assumed for the interior of the puddling furnace, and the gases cannot therefore be any cooler than this. 4.207 being the number of heat-units in the escaping gases for every degree F. of their temperature, the quantity of heat carried off for each pound of coal consumed is $2900 \times 4.207 = 12{,}200$ units per lb. of coal. 2016 lbs. of coal having been used, we get $\frac{2016 \times 12{,}200}{14{,}133} = 1740$ lbs. as the quantity of coal the combustion of which equals the quantity of heat escaping from the puddling furnace by the waste gases, and this represents $\frac{1740 \times 100}{2016} = 86$ per cent. of the total coal consumed per ton of iron.

Similarly in re-heating furnaces—assuming a temperature 500° F. lower for the escaping gases—there are $2400 \times 4.207 = 10{,}097$ units per lb. of coal escaping, and this equals the combustion of $\frac{896 \times 10{,}097}{14{,}133} = 640$ lbs. of coal, or equivalent to $\frac{640 \times 100}{896} = 71$ per cent. of the total coal consumed per ton.

Where gas furnaces are not used, either of two methods of recovering some of the waste heat has been employed. These are, raising steam by means of the heat of the waste gases, by leading them through boiler flues on their way to the chimney; and transferring some of the heat of the waste gases to the air for combustion in the furnace.

The first method is common in forges and rolling mills, and is applied with both vertical and horizontal boilers, the latter being safer, but requiring generally more floor space and a greater first cost.

The second method has also been successfully carried out with proved economy in fuel. Very good examples of this method will be found in the interesting furnaces used by M. Sudré for steel making,* the furnaces of Caddick and Mabery,† Perkins and Smellie, and the "Newport" furnace of Mr. Jeremiah Head.‡

The following figures show respectively a side elevation, longitudinal and transverse sections, and sectional plan of the air furnaces used by M. Sudré for melting large quantities of steel, Figs. 559 and 560 referring to one form, and Figs. 561 and 562 to another arrangement of furnace.

These furnaces were constructed at the instigation of the late Emperor of the French, Napoleon III., and they are remarkable for the results which they yielded. Until the introduction of the Siemens open-hearth furnace, the largest masses of steel ever melted in single charges were obtained from the furnaces of M. Sudré.

In Figs. 559 and 560 there are preparatory ovens or chambers at the chimney end of the furnace, in which ovens the charge was placed previous to its being melted on the hearth of the furnace. This furnace is shown as arranged to be worked by means of a blast of air, instead of by chimney draught, this having been found to increase the intensity of the heat produced in the furnace. The charges of steel to be melted were covered with a layer of glass, which, when melted, protected the steel from oxidation as well

* Crookes and Röhrig's "Metallurgy," vol. iii. p. 259; Siemens in "Jour. Chem. Soc. Lond.," July 1868; W. Mackenzie's "National Encyclopædia," art. Furnaces.

† D. K. Clark, on "Fuel, its Combustion," &c., pp. 284, 285; "The Engineer," Sept. 21, 1877, p. 210.

‡ "Jour. Iron and Steel Inst.," vol. i. 1872, p. 220; D. K. Clark, *op. cit.*, pp. 271, 273.

as from contamination by sulphurous and other gases given off from the fuel. The charge, when melted, was tapped and run out by means of the inclined spout shown in Fig. 559.

Fig. 559.

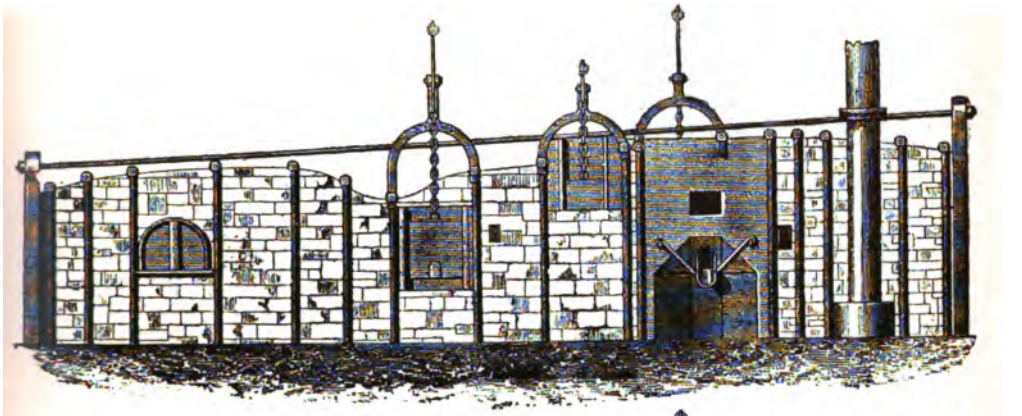


Fig. 560.

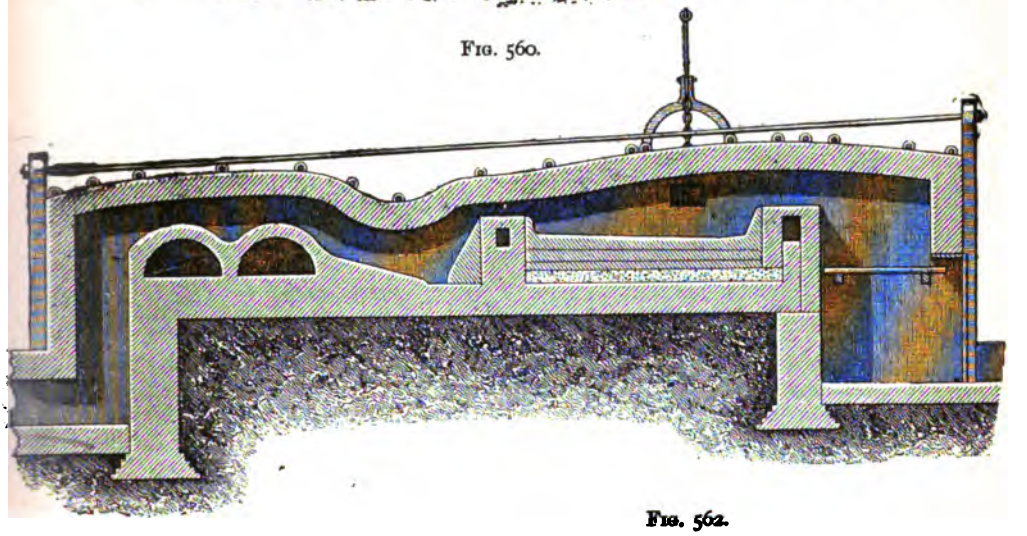


Fig. 562.

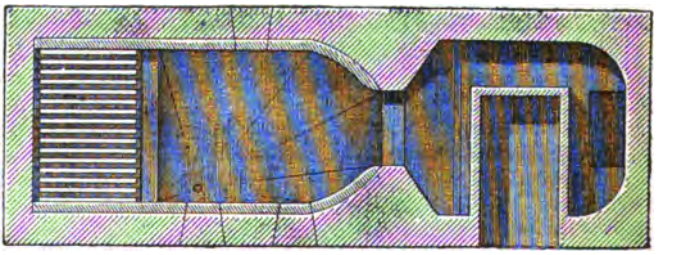
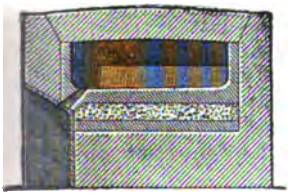


Fig. 561.



In the furnaces of Messrs. Perkins and Smellie, and of Mr. Head, the air supply is delivered by means of steam-jet blowers, and boilers for steam raising are also used in order to recover more heat from the waste gases than is extracted in heating the air supply.

The economical advantage in heating the air supply in this way may easily be calculated. It has been stated to be 13.4 per cent. or about 1 cwt. in 8 cwts. when the air is heated to 500° F., and 27 per cent. or 1 cwt. in 5 cwts. when the air is heated up to 1000° F.

It is readily understood that when this quantity of heat is abstracted from the waste gases they cannot be so efficient for steam raising as if used without this preliminary cooling.

The distribution of the heat of combustion of the coal used in puddling and in heating furnaces, when a portion of the waste heat was utilized in raising steam, was carefully investigated by M. Ponsard,* at ironworks in the North of France. He found, as an average result, that 1 lb. of coal burned on the grates of re-heating furnaces yielded 2½ lbs. of steam from horizontal boilers heated by waste gases, and his results, which are given in the following table, show generally that puddling and heating furnaces with large charges utilize, in heating iron and generating steam, about 40 per cent. of the total heat of combustion of this fuel and lose about 60 per cent. Part of what is put down as "loss" is no doubt necessary use, although not directly employed in imparting heat to the iron, because it is impossible to heat the iron without heating also the chamber or receptacle which contains it.

Distribution of Heat.	Puddling Furnace.		Heating Furnace.	
Used—	Cwts.	Per Cent.	Cwts.	Per Cent.
Directly utilized, absorbed by the iron . .	0.75	4¼	0.75	9¼
Recovered by generating steam . . .	6.00	33	2.67	33
Total fuel utilized . . .	6.75	37¼	3.42	42¼
Lost—				
Loss by the chimney	9.54	53	3.04	38
Loss by radiation and conduction . . .	1.71	9½	1.54	19¼
Total fuel lost	11.25	62¾	4.58	57¼
Total fuel consumed	18.00	100	8.00	100

Fig. 563 is a ground plan of a smelting furnace for lead ore, which shows the peculiar manner in which the bottom of the furnace slopes to one point, so as to allow the lead to run off as it is produced. The arch is very low, and throws the flame down on to the ore in a manner peculiar to this operation.

The furnaces employed for the refinery of silver may be worked by an ordinary blast, but a steam-jet employed as shown in Figs. 564 and 565 has been found to answer equally well. The fuel is thrown into the fire-place *a*, and the flame passes over the bone-ash test *b*, which serves the double purpose of forming the bottom of the furnace and a bath for the molten lead. The lead is run into the test from a pan *c* through a small pipe *d*. The fire-bridge and chimney are shown at *e* and *f*. A small door *g* allows the workman to inspect the progress of the refining, the state of the test, and to facilitate the overflow of the oxide of lead as it is formed and blown forward by the air and steam-jet entering at *h*. The iron hood and pipe, *i*, *k*, serve to convey any metallic fumes which escape during this inspection to the chimney or main flue.

As another illustration of the application of fuel in metallurgical operations, Fig. 566 represents the furnace employed in Belgium for the reduction of zinc ores. The furnace is in the form of a rectangular prism, in which

* *Mémoires, &c., de la Société des Ingén. Civils*, 1874; Percy, "Metallurgy," vol. Iron and Steel, p. 691; D. K. Clark, *op. cit.*, p. 262.

are ranged altogether about 46 clay tubes, in 8 rows, inclined towards the front of the furnace, where they deliver the volatile metal into cast-iron

FIG. 563.

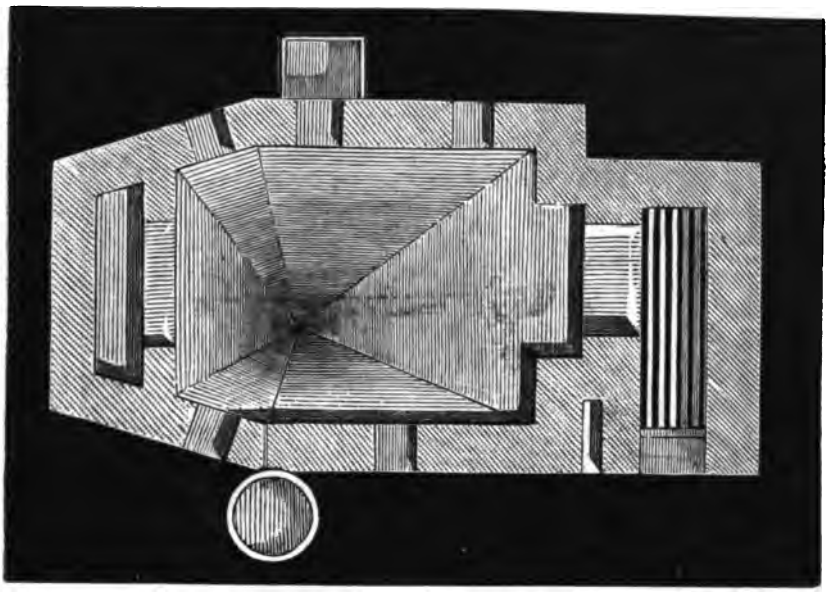
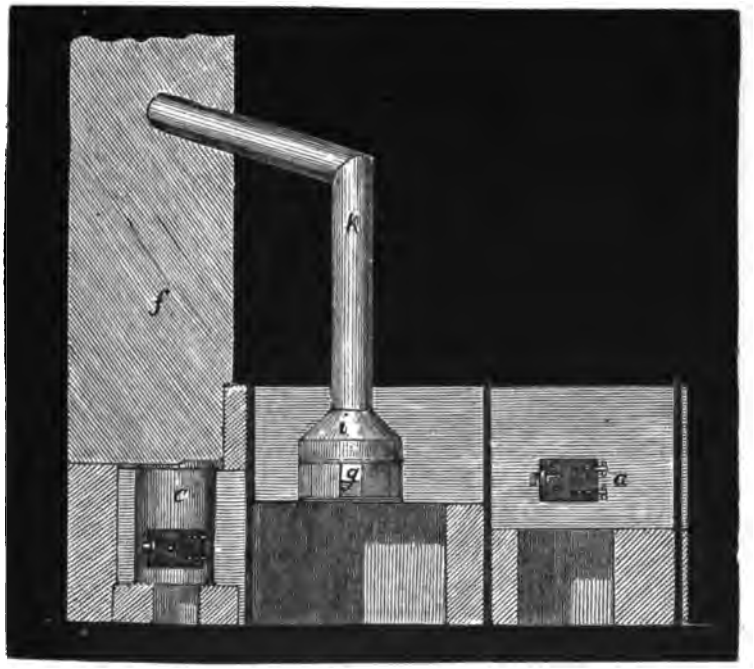


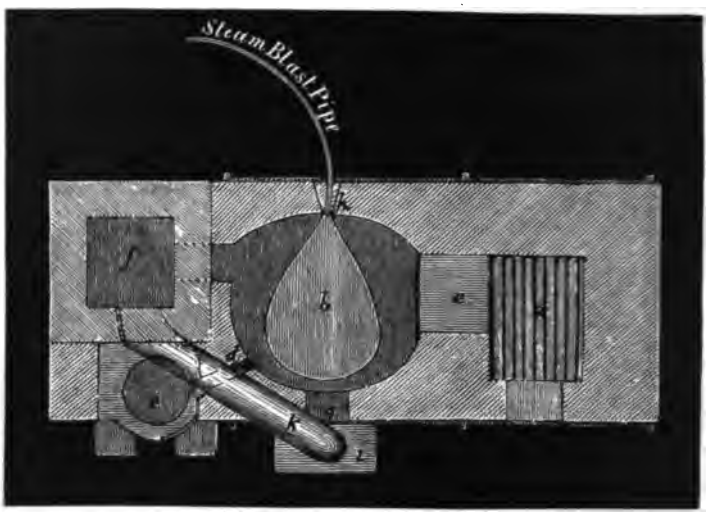
FIG. 564.



pipes, and thence into sheet-iron receivers. The single fire is placed at *A*, and the flame plays round all the clay vessels, which are charged with roasted ore and charcoal.

Before leaving the subject of furnaces which employ solid fuel, reference must be made to several ingenious attempts to make use of that fuel in the

Fig. 565.



state of powder or dust. This is evidently a great step towards gaseous fuel, and, as might have been expected, some very excellent results were obtained with the system. Various small practical difficulties have however interfered with its extended or long-continued use.

Fig. 566.

First proposed by Mr. John Bourne in 1857 (see Patent Specification of that year, and "Treatise on the Steam Engine," p. 358), it was made a practical success by Mr. T. R. Crampton, who energetically worked at it until it became apparent that it could not be universally adopted (see "Jour. Iron and Steel Inst.," 1873, p. 91; 1874, p. 391; *Mém., &c., de la Soc. des Ingén. Civils*, 1875, p. 266).

Other attempts were made by Whelpley and Storer in America (see B. Isherwood; T. A. Price in Report of Board of Trade of Scranton, Pa., for 1886; D. K. Clark, *op. cit.*, p. 345), G. K. Stevenson in London (see "The Engineer," May 18, 1877, p. 336; D. K. Clark, *op. cit.*, p. 346), and latterly by Perrett in a new system of furnaces (see "Engineering" of July 1886).

Gas Furnaces.—The fact that the production of flame demands the existence of fuel in the gaseous state points unmistakeably to the necessity for gas furnaces, and an examination of this system shows it to be the only really economical method of dealing with fuel. The economy is due partly to the facility which is afforded for regulating the supply of air needed for combustion, and thus getting rid of nearly all the immense excess of it which invariably accompanies the use of solid fuel; partly to reduced loss by conduction and radiation in consequence of combustion being effected in that

part of the furnace where the application of heat is desired, instead of in a grate at some distance from it; and in great part to the recovery of waste heat which is possible to a great extent when gaseous fuel is used. Dealing with only a portion of what may be realized from these sources of economy, Mr. D. K. Clark* has published the following interesting calculation:—

With regard to the effect of reducing the quantity of surplus air required for complete combustion of the fuel, there is reason to believe that, under proper regulation, the excess admitted need not exceed 10 per cent. of the quantity chemically consumed. The temperature of the products of combustion must be relatively higher, as may be shown by the following figures:— From 1 lb. of coal there are 11.94 lbs. of burned gases, having a specific heat of 0.246; the surplus air is 10 per cent. of 10.7 lbs. (the weight of air chemically required), or 1.07 lb., of which the specific heat is 0.2377. Then

From 1 lb. Coal.	Weight.		Sp. heat.		Units.	
Burnt gases . .	11.94 lbs.	×	0.246	=	2.935 per 1° F.	
Surplus air . .	1.07 ,,	×	0.2377	=	0.254	,,
	13.01 ,,	×	.245	=	3.189	,,

The temperature of combustion therefore amounts to—

$$\frac{14,133}{3.189} = 4432^\circ \text{ F. above, say, } 62^\circ.$$

This temperature is 1075° above what is produced when the surplus air amounts to 50 per cent., and is in the ratio of 3359° to 4432° or 1 to 1.32; that is to say, the gain of temperature from this cause is 32 per cent. If the useful performance be in the same proportion, the same quantity of puddled iron would be produced by a reduced consumption of $\frac{1}{1.32} = \frac{3}{4}$ths of the coal which was used with 50 per cent. excess of air, or a saving of 25 per cent. in fuel.

The economy arising from preliminary heating of the air by waste heat is less proportionately in these furnaces on account of the smaller quantity of air per lb. of coal to be heated. That quantity being 10.7 + 1.07 lbs. = 11.77, or, say, 12 lbs., absorbing 119 units of heat per lb. for an increase of 500° F., the total heat so applied amounts to 119 × 12 = 1,428 units per lb. of coal, or $\frac{1,428 \times 100}{14,133}$ = 10 per cent. of the total heat of combustion of 1 lb. of coal, or a saving of 9 per cent. For an increase of 1000° F. in the temperature of the air the saving is 17 per cent.

Combining the economies thus estimated, Mr. Clark states that the consumption of coal may be reduced to about two-thirds, so that if furnaces used 18 cwt. per ton of iron for puddling and 8 cwt. per ton for heating, their work may be performed with about 12 cwt. and 5 cwt. respectively, "estimates, the reasonableness of which has been amply demonstrated by experience."

Lower rates of consumption than these are, however, common with gas furnaces, and the further economy is no doubt due to the perfection of the methods of recuperation of heat (possible only with gaseous fuel), to increased intensity of combustion, the effect of having highly heated gas and air, and to diminished waste by chimney gases.

In general, gas furnaces may be divided into two classes—viz., (1) those which have a gas-producer (or gas-producing fire-place) attached to and forming part of the structure of each furnace, and (2) those which are

* "Fuel, &c.," p. 266.

entirely distinct from the apparatus in which gas is produced, the gas being conveyed to them by flues or pipes.

In one or other of these forms, gas furnaces have been known and used for upwards of forty years—the early producers of Bischof, Ebelmen, Ekman, and Thomas and Laurens (see pages 250-2 *ante*) were used in connection with such furnaces during the years 1839 to 1845—even if we omit the earlier labours of Faber du Faur and others in this field (see page 226 *ante*). An early form of gas furnace, at Treveray, in France, is mentioned by Péclet;* Mr. D. K. Clark† refers to the long-continued employment of gas furnaces on the Continent, particularly in Styria; and Mr. H. Bauerman‡ remarks that "gas furnaces existed long before they were so called. There was the old hollow fire for re-heating the tin-plate forges, and also used in Sheffield, which was employed at a very early period—early in the eighteenth century, and perhaps before that time. There was also the South Wales reverberatory furnace, whose fire-place, with the clinker grate, was essentially a gas producer."

It appears from a statement made by Dr. Lunge,§ that "on the Continent there seems to be a general tendency towards attaching the producer to the furnace, and thus converting by suitable modifications the ordinary fireplace into a gas producer." The reasons which induce the adoption of this class of gas furnaces are said to be the saving in first cost and in space, and the prevention of loss of heat by radiation during the passage of the gas from separate generators to the furnaces.

The furnaces referred to by Dr. Lunge are probably constructed either without heat recuperators or with means for effecting continuous recuperation in some degree, as it would be extremely difficult to adapt such gas producers to the Siemens arrangement of furnaces, which, for high temperatures, is the most economical, although originally the Siemens furnace was designed for solid fuel. As compared with an equal number of Siemens furnaces, no doubt the furnaces referred to may cost less to build, but the attachment of a gas producer to each furnace causes a greater outlay per furnace than where several of the same kind of furnaces are built so as to be fed from a common gas supply. Moreover, in the event of any furnace being laid off for repairs, or for other reasons, the gas-producing plant also becomes unproductive. This system of working involves the distribution of the fuel to many points, and the multiplication of stokers, as against the concentration of both fuel and labour where the system of separate generators is adopted, the generators being grouped together as is convenient.

The loss of heat consequent on the use of generators separated from the furnace has been frequently over-estimated. Dealing with the Siemens sloping-grate producer, G. J. Snelus‖ has estimated the actual loss as follows:—"The number of units of heat produced by the transformation of a unit of carbon into carbonic oxide is, according to the best results, about 2,400. In order to obtain the resulting temperature, by theoretical reasoning we have to take into consideration the effect of specific heat, a subject which still requires much experimental elucidation before satisfactory results can be obtained by calculation. There is, however, sufficient reason to know that this quantity is variable, and that it increases with the temperature. Judging from the specific heat obtained at low temperatures, and the law of increase which it appears to follow, the mean specific heat of nitrogen between 0° and 1000° C. may be given as about 0.38, and that of carbonic oxide as about 0.35. Hence, it follows, that the resulting tem-

* *Traité de la Chaleur.*
† "Fuel, &c.," p. 237, see also "Jour. Iron and Steel Inst.," vol. i. 1884, p. 60.
‡ "Min. Proc. Inst. C.E.," vol. lxxxiv. p. 60.
§ *Ibid.*, p. 93. ‖ Article Fuel, Mackenzie's "Chemistry."

perature of transformation of carbon into carbonic oxide burning in the atmosphere is—

$$\frac{2{,}400}{4.46 \times .38 + 2.3 \times .35} = \frac{2{,}400}{2.5139} = 960° \text{ C.}$$

"From experiments which have been made in different states of the producer, as managed with more or less care, the temperature of the gases at the foot of the off-take from the producer appears to vary from 300° to 500° C., or, taking the mean, 400° C.

"The difference between 960° and 400° is 560°, and the number of heat-units representing this difference of temperature is $\frac{560}{960} \times 2{,}400 = 1{,}400$ units, which have been employed in the distillation of the hydrocarbons contained in the coal and in the decomposition of the steam supplied below the grate, thus enriching the resulting gases to exactly the same amount—the heating power of the hydrocarbons produced being the exact equivalent of the heat-units employed in their production.

"It has been frequently stated that the action of the gas-producer is such as to cause a loss of heat of 30 per cent. of the total heat available, carbon producing 8,080 units by perfect combustion into carbonic acid, and carbonic oxide absorbing 2,400 units in its production. It must be remembered, however (and this is where the error in the statement exists), that this loss corresponds with a resulting temperature of 960° C. (for if the carbonic oxide were at once utilized in the furnace at its temperature of production no heat would be lost), whereas experiments give a mean of 400° C. as that of the producer gas. The loss therefore in the producers is reduced from 30 per cent. to a mean of $\frac{400}{960} \times 30 = 12\frac{1}{2}$ per cent., and a minimum hitherto attained of $\frac{300}{960} \times 30 = 9\frac{3}{8}$ per cent. It is, however, possible so to work the producers as to recover in the form of hydrocarbons and mechanical energy nearly the whole of the 30 per cent."

In producers worked by means of steam blast, it is found* that a lower temperature of combustion, and of the resulting gases, is obtained than where air blast alone is used, the effect of which is to give a smaller range of temperature through which loss of heat can occur during the passage of the gases through the flues from producers to furnaces, and this reduced loss of heat balances the expenditure of heat in producing and decomposing the steam. There are doubtless circumstances in which it may be convenient to have a gas-producer or gas-producing fire-place for each furnace, and it is undeniable that this was an early form of gas furnace, and that it has done good work.

In order to obtain the highest temperatures of combustion with ordinary producer gas, it is necessary to have a supply of heated air for combustion. If, however, the nature of the operation carried on in the furnace is such as to permit the accumulation of heat there, a high temperature may be maintained in a furnace which is worked with producer gas, and air at atmospheric temperature. Furnaces worked by Albright and Wilson under these circumstances which had their temperature observed daily during some months by means of the Siemens copper and platinum ball pyrometer showed a temperature of of 2800° F. The gas used was from Wilson's producers. To ensure rapidity of combustion, the air and gas should both be heated to about the same temperature, and if this is near the temperature of ignition so much the better. This heating is usually effected by means

* *Chem. Centralblatt*, vol. xv. p. 414.

of waste heat or the heat derived from the products of combustion after they have done their duty in the combustion-chamber, and the various systems of thus applying that heat have been styled "regeneration," "recuperation," or "restoration." In some cases, the air for combustion of the gas is heated at the expense of the combustion taking place in the furnace itself; and Ponsard, and one or two others, have tried heating the air delivered into the gas-producer. This latter plan shows good results when the producer is attached to the furnace so that the full benefit of the higher temperature of the gas thus produced can be realized in the furnace. Otherwise, where the gas is conveyed some distance, or where reversing regenerators are employed, there is no saving in this high initial heat of the produced gas.

There are three kinds of "regenerators" in use:—

First, those composed of metal (usually cast-iron) for continuous conduction of the heat.

Second, those composed of fire-brick for continuous conduction.

In these two classes, the hot waste gases and the supply of air for combustion are usually made to travel in opposite directions in passages which are separated from each other by a thin partition, the heat being transmitted through the material of which the regenerator is constructed. One surface is thus continuously in contact with the hot waste gases, and the other surface with the air being heated.

Third, reversing regenerators of fire-brick so arranged that the same surfaces which are heated by contact with the outgoing hot gases, are on the reversal of the direction of the currents of air and gases, placed in contact with the incoming air or gas, or both, which are passed over them and thus heated.

The first mention of continuous heat regeneration or conservation on record is contained in a patent dated 1831, which is referred to by Percy,* and describes a continuous regenerator formed of iron plates. Both Percy† and Siemens,‡ however, give to Stirling, the inventor of the hot-air engine, the credit of being the father or originator of the regenerative principle, Stirling's patent of January 20, 1817, fully describes the reversible regenerator as applied to his hot-air engine and to furnaces and appliances for the combustion of fuel generally.

Ekman used continuous regenerators of iron in his gas furnaces in 1843, and Richard Laming, in a patent taken out in 1847, described a continuous recuperator constructed of iron tubes which is supposed by Mr. Charles Hunt§ to be the earliest continuous recuperator known. Both Slater (in 1831) and Ekman (in 1843), however, preceded him in this special direction.

But little has been done by way of investigating the relative efficiency of these different systems of regeneration. Certain advantages and disadvantages in each are apparent on the surface, and the choice of the kind which is to be used is in general decided by considerations of convenience or of cost.

The continuous regenerators have the advantage of cheapness of construction in comparison with the other system, and they have also the recommendation that they dispense with valves and complication of passages. It is the opinion of leading gas engineers that it is this system which has rendered practicable the application of gaseous fuel to the heating of the retorts in gas works.

On the other hand, they are open to the objections that fire-brick is not a good conductor of heat, and if rapid conduction is secured by the use of iron as the material of which the regenerator is constructed, this is done at the cost of durability.

* "Metallurgy," vol. Fuel, p. 532. † *Ibid.* p. 595.

‡ On the Conversion of Heat into Mechanical Work: "Min. Proc. Inst. C.E.," vol. xii., 1852-3. § See "Jour. Soc. Chem. Ind.," 1884, p. 89.

As to fire-brick, however, M. Sylvain Périssé has shown* that the coefficient of conductivity of burnt fire-clay, and especially of good fire-brick, increases with the temperature, so that careful measurements of the heat of the air after passing through the Ponsard recuperator proved that it had acquired temperatures ranging between 1000° and 1100° C. (1832° and 2012° F.).

As regards the durability of a cast-iron pipe regenerator, experience gained with the hot-blast stoves of iron smelting furnaces over many years has proved, first, that of all forms of wrought or cast iron the most durable is a cast-iron pipe, either cylindrical or oval and of moderate dimensions as regards cross-sectional area; secondly, that heating stoves composed of cast-iron pipes will stand from five to ten years subjected to a temperature which heats the air passing through them to 1000° F.†

The reversing regenerators of Siemens are theoretically the most perfect, and, as a counterpoise to their greater first cost, they are undoubtedly the most durable in practice. There is in them no loss occasioned by having to transmit the heat, their action being alternately that of simple *accumulators* (which is the proper name for them) absorbing the waste heat from the escaping gases, which heat they subsequently give up from the same surfaces to combustible gases or air.

Mr. C. W. Siemens‡ in describing their action said, "the amount of brickwork required to absorb the waste heat of a given furnace is a matter of simple calculation. The products of the complete combustion of 1 lb. of coal have a capacity for heat equal to that of nearly 17 lbs. of fire-brick, and (in reversing every hour) 17 lbs. of regenerator brickwork at each end of the furnace per lb. of coal burned in the gas producer per hour would be theoretically sufficient to absorb the waste heat, if the whole mass of the regenerator were uniformly heated at each reversal to the full temperature of the flame, and then completely cooled by the gases coming in. In practice, however, by far the larger part of the depth of regenerator chequer-work is required to effect the gradual cooling of the products of combustion, and only a small portion near the top, perhaps a fourth of the whole mass, is heated uniformly to the full temperature of the flame; the heat of the lower portion decreasing gradually downwards nearly to the bottom. Three or four times as much brickwork is thus required in the regenerators, as is equal in capacity for heat to the products of combustion.

"The best size and arrangement of the bricks is determined by the consideration of the extent of opening required between them to give a free passage to the air and gas, and by the rule, deduced from my experiments on the action of regenerators in 1851–2,§ that a surface of 6 square feet is necessary in the regenerator to take up the heat of the products of combustion of 1 lb. of coal in an hour."

In his experiments with the heated-air engine, Siemens found a loss of one-twentieth of the heat in the regenerators, when the experiments were very carefully conducted and the maximum efficiency was obtained.

This is considered by Snelus‖ to be too small an allowance for ordinary practice with the regenerators of furnaces, and he accordingly assumes the loss at one-fifteenth in the following calculation of furnace efficiency:—

"In order to calculate at any moment the efficiency of a heat engine,

* Sur le Four à Gaz avec Récupérateur de Chaleur, Système Ponsard: *Mém. et Compt. Rend. des Travaux de la Soc. des Ingén. Civils* (Paris), vol. for 1874, pp. 752–812, and vol. for 1875.

† On Regenerative Gas-firing for Retorts, by A. Wilson: "Proc. N.B. Assoc. of Gas Managers," July 1881.

‡ On the Regenerative Furnace as applied to the Manufacture of Cast Steel: "Jour. Chem. Soc.," July 1868.

§ "Min. Proc. Inst. C.E.," 1852–3, p. 571.

‖ Mackenzie's "Chemistry," &c, article Fuel, p. 977.

and there is no reason why a metallurgical furnace should not be treated in the same manner, all that is requisite to know is the maximum temperature and the range of temperature. The minimum is easily obtainable, and the maximum temperature may also be obtained by experiment. It has been so obtained with the electrical pyrometer already described, and has been found to be 1611° C. or adding 274°, the distance of the zero centigrade from the absolute zero of temperature, 1885° absolute.

"The temperature at which the waste gases leave the chimney is never above 170° C. or 444° absolute.

"The range of temperature is $1885° - 444° = 1441°$, and the ratio of this to 1885 + one-fifteenth for loss in the regenerators is $\frac{1441}{1885 + 141} = \frac{1441}{2026} = 71$ per cent. of efficiency.

"In the steel-melting furnace, and allowing the maximum temperature to be 2000° C. equivalent to 2274° absolute, the range of temperature is $2274° - 444° = 1830°$, and the efficiency $\frac{1830}{2274 \times 169} = \frac{1830}{2443} = 75$ per cent. of efficiency."

As regards the amount of heat used in steel-making in crucibles, Snelus says that it appears "that the regenerative gas furnace produces in manufactured steel about 18 per cent. of the theoretical equivalent of the fuel, and the Sheffield coke holes about 9 per cent."

Analyses of the performance of Siemens furnaces melting glass and heating iron piles have been published by M. Kraus in his paper, "Etude sur le Four à Gaz et à Chaleur Régénérée," in *Annales du Génie Civil*, 1874, p. 36, an abstract of which is given in English by Mr. D. K. Clark.* The following is a summary of the estimate of the distribution of the heat of 37½ kilograms of coal, the quantity consumed during each interval of half an hour—the regenerator valves being reversed each half-hour.

	Calories.	Per Cent.	Calories.	Per Cent.
For the conversion of the fuel into gas			102,593 or	31.7
Loss by chimney	25,000 or	7.7		
Loss through walls of regenerators	27,750 or	8.6		
Absorbed by the iron	55,500 or	16.5		
Lodged in the furnace and loss through walls	112,766 or	35.5		
			221,016 or	68.3
			323,609 or	100.0

Figs. 567 and 568 illustrate a very early gas furnace arranged with an attached gas producer and used for puddling or heating iron in Sweden probably about forty years ago.

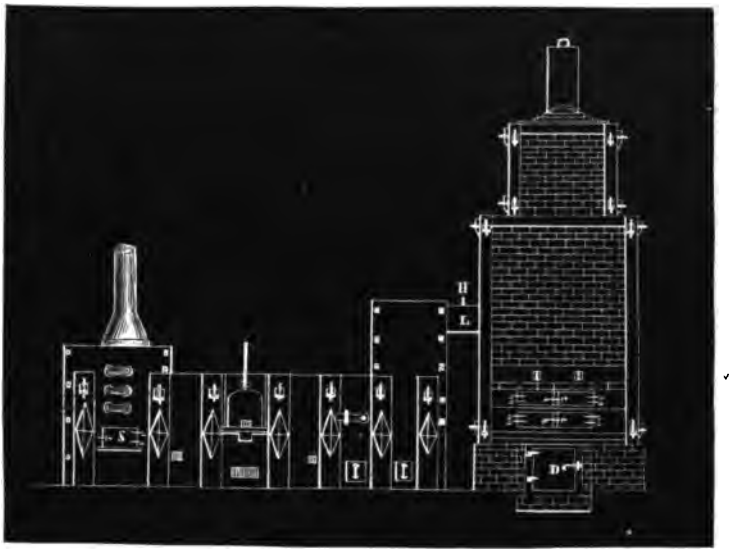
It combines also in its arrangements the features of a gas producer worked by blast, continuous regeneration of heat by means of iron pipes exposed to the heat of the waste gases and used to heat the incoming air supply, and forced or blow-pipe combustion carried on in the furnace by means of this heated blast of air.

The gas-generator consists of the grate, ash-pit, and door, *A*, *B*, and *D*, the air being supplied through a tube *C*. The space *E* is filled with red-hot fuel, where the carbonic acid is converted into carbonic oxide. The gas accumulates at *F*, and is conveyed away by the flue *G*, in which a damper *H* is placed. The shaft *I* is wider at the bottom, which prevents the fuel hanging to the sides, and is furnished with two small openings *K*, *K*, by which the height of the fuel is observed, or through which it is broken up from time to time. The other details are fully shown in the drawing.

* "Fuel, its Combustion," &c., p. 306.

In the illustration, the gas passes through the flue *L* into a chamber *M*, where the dust and mechanical impurities are deposited, which are removed

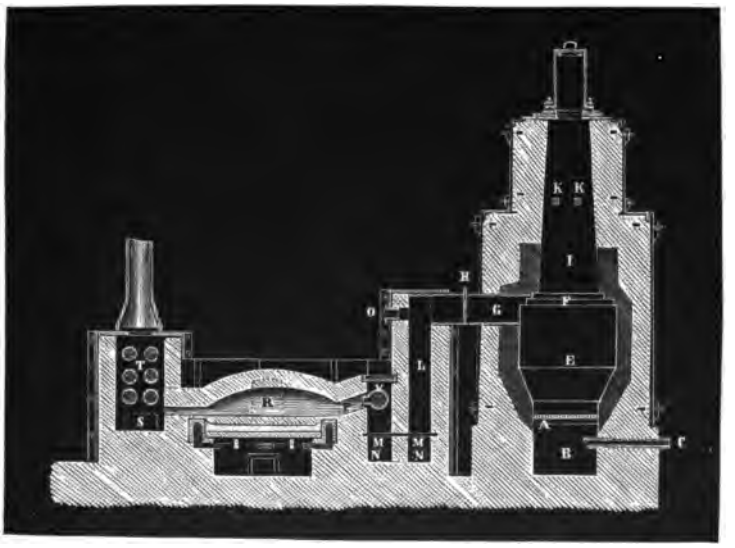
Fig. 567.



at intervals through the openings *N* or *O*. The gas is not ignited immediately as it issues from the nose-pipes, but passes over a bridge *P* into the hearth of the furnace *R*.

The blast is partly heated by a small fire at *S*, and partly by the waste

Fig. 568.



gases passing round the pipes *T*, which communicate with the pipe *V*, extending the whole length of the gas-flue, and which is furnished with 7 to 11

nose-pipes. Those gases which contain least aqueous vapour are most easily ignited, and produce the greatest heat.

Gas furnaces of this description were used as early as the year 1845 in Sweden. Two forms worked by Ekman are given by Percy in his work on Metallurgy.* Another arrangement which was introduced rather later into works in Björkeberg and Storfors in Wermland † is shown in Figs. 569, 570, 571, 572. This furnace had a rectangular gas-producer, designed for using charcoal, into which heated blast was delivered by two rows of tuyeres.

Fig. 569.

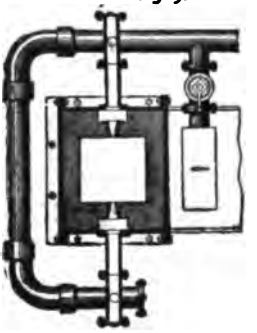


Fig. 570.

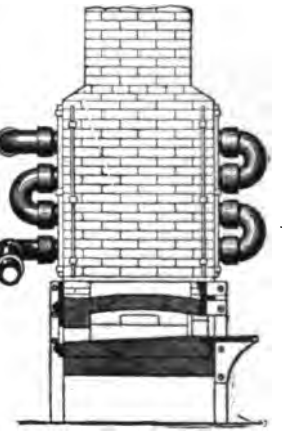
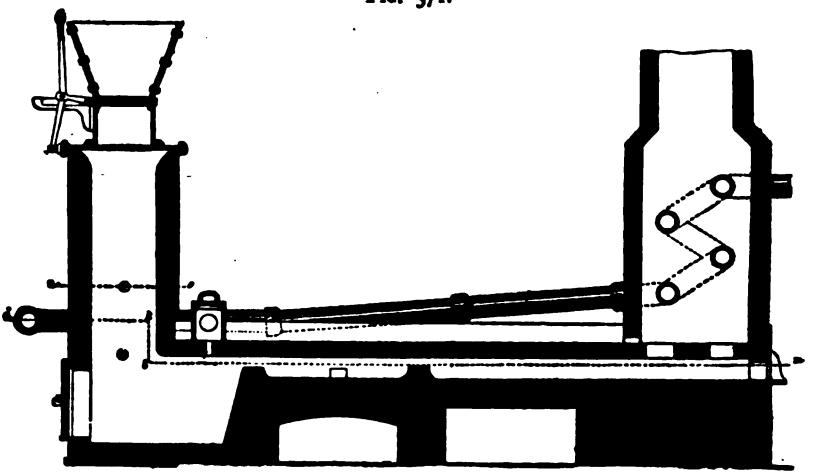


Fig. 571.



The gas escaped from the producer below the tuyeres, and entering the furnace was met by a further supply of hot-air delivered through openings in the furnace-roof. The waste heat was used to heat the blast in its passage through a coil of cast-iron pipes placed in the chimney.

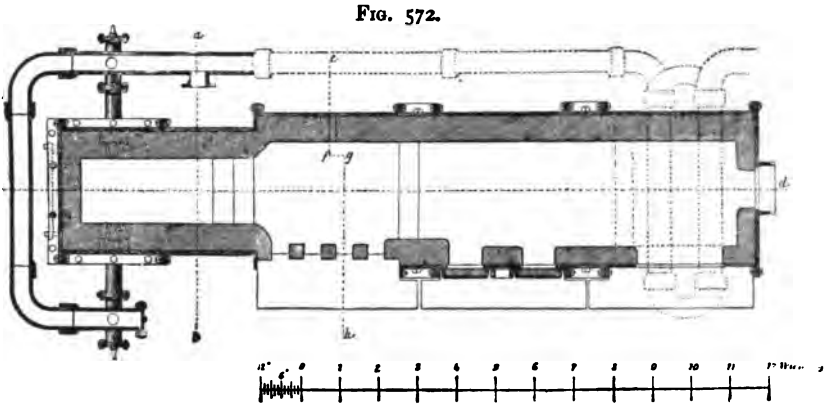
Figs. 573, 574, 575, illustrate an improved gas-furnace for wood as fuel which Tunner saw at work in Lesjöfors in the year 1857. Fig. 573 is a

* Vols. "Fuel," pp. 518–523; "Iron and Steel," pp. 716–720.

† Tunner's *Eisenhüttenwesen in Schweden*, pp. 52–65, plates iii., iv., and vi. (Freiberg, 1858).

horizontal section on the line AB, Fig. 575; Fig. 574 is a vertical section on the line LMNO, Fig. 573; and Fig. 575 is a plan in section on the line GHJK, Fig. 573. In this case, the blast was heated in the bell-shaped iron chambers *b b*, entering them at *a*, and passing from them by the passage *c* to *d d* and *e*, whence it passed partly into the producer *f*, and partly by the pipe *h* to *g*, in order to supply air for combustion. The wood was charged into the producer through the opening *g*, and the flame and

FIG. 572.

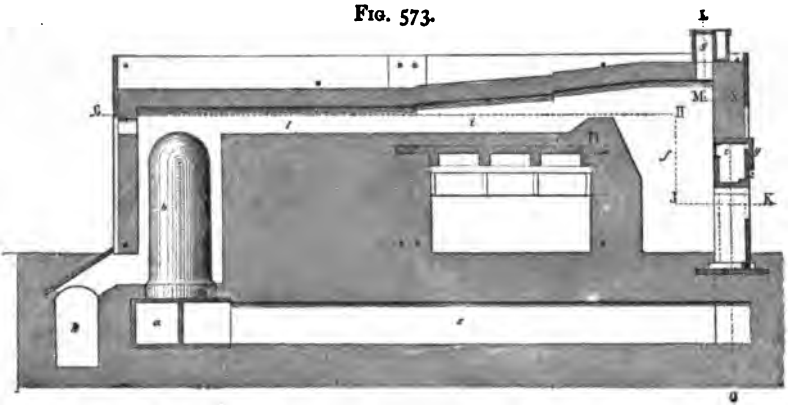


hot gases passed over *i* and *l* to the flue *k*, whence they were led to drying ovens for the wood.

A furnace which bears some resemblance to this one was illustrated in "Engineering" (January 28, 1870), as having been introduced into the Newport Iron Works at Middlesbrough.

Another interesting furnace, which may be classed among pioneer gas-furnaces, is illustrated by Dr. Percy ("Fuel," p. 517), from a drawing

FIG. 573.



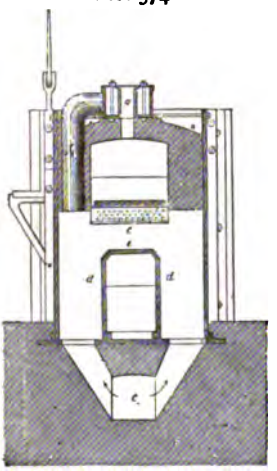
supplied by Dr. H. Wedding, of Berlin, this furnace having been used in the Mint and Royal Porcelain Manufactory at Berlin in 1861.

In all these instances, the use of gas along with a blast of air, either heated or cold, producing in fact a blow-pipe flame on a large scale, is found. This system seems to have been introduced first in Sweden. Dr. Percy gives* a report from Mr. Sandberg on the working of Ekman's furnace

* "Metallurgy": Iron and Steel, p. 427.

which illustrates the practical differences found in working with cold- and with hot-air blast. Cold air gives a long blue flame, not hot enough to weld iron unless continued for some time, whilst hot air gives a short, white, and hot flame, able to melt wrought-iron with facility. This result is due to the combustion being more rapid and complete with the hot air, the consequence of its higher temperature.

Fig. 574.

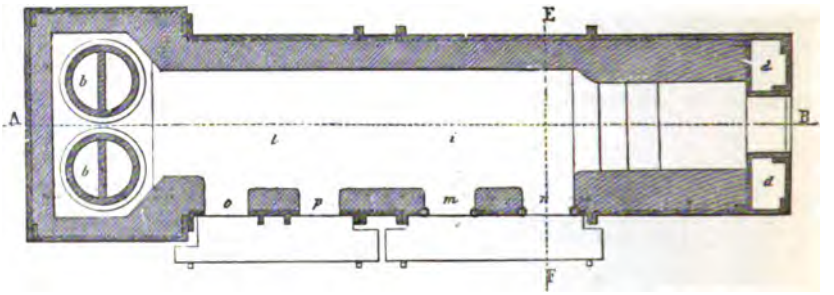


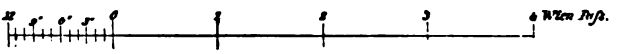
In the Supplement to Dr. Ure's "Dictionary of the Arts," &c. (article Iron), London, 1846, some gas blow-pipe furnaces for iron manufacture are illustrated. M. Péclet also gave* full details of a gas furnace worked on the blow-pipe system with waste gas from iron furnaces, at Treveray, in France, at an early date, and illustrations of it are given in the work of Mr. C. Wye Williams.†

The blow-pipe system seems to have been almost entirely neglected in Britain for many years. Mr. Sutherland proposed in 1869 some ingenious plans for welding by gas with blast, which were subsequently practised to some extent in the works of a firm of tube-makers.

A very successful use of the blow-pipe system was made in the ingenious puddling apparatus of Godfrey and Howson.‡ Figs. 576 and 577 illustrate

Fig. 575.





this apparatus, Fig. 576 being a sectional side elevation showing the gas main, air-pipe, air-heater, and compound blow-pipe delivering its flame into the rotating puddler. The flame and waste heat escaping from the puddler ascend through the stack of cast-iron air-pipes placed in an upright chimney which can be closed by a damper. The arrows in the illustration show the course of the flame and gases. Fig. 577 is a front elevation of the whole apparatus.

* *Traité de la Chaleur.*

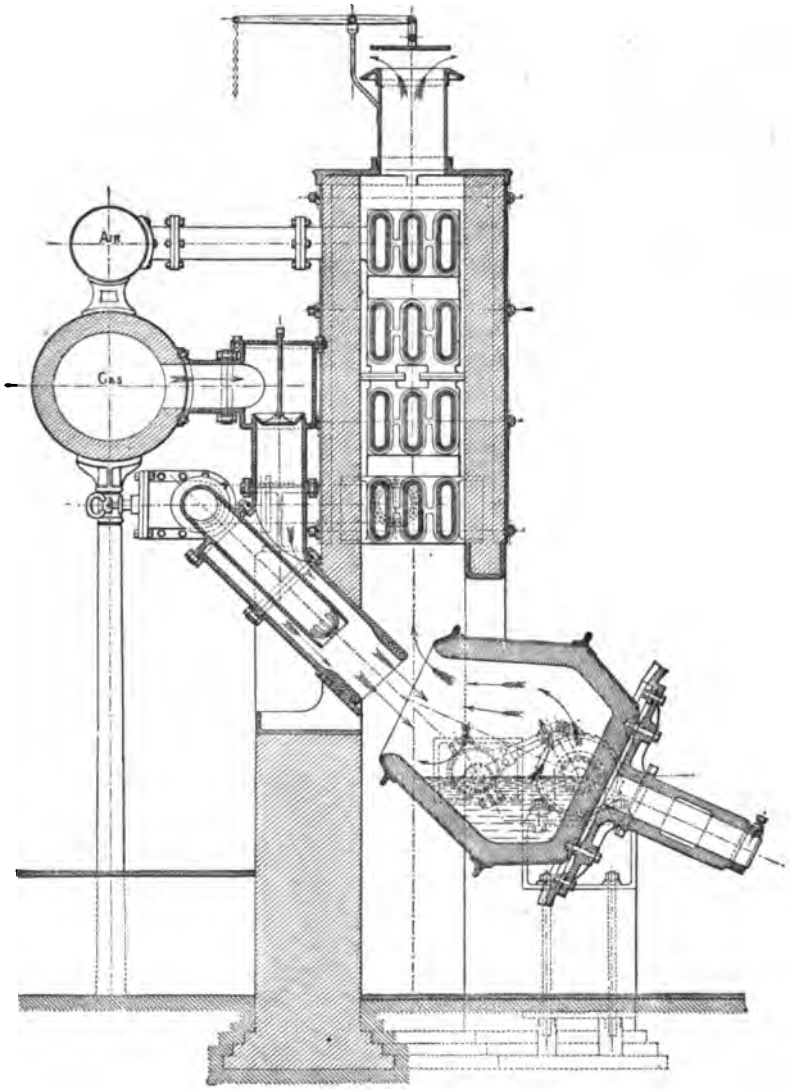
† "On the Combustion of Coal," &c., first edition, p. 68; "Fuel, its Combustion and Economy" (Williams and Clark), second edition, pp. 45–47.

‡ R. Howson in "Jour. Iron and Steel Inst.," vol. ii. 1877, see also *ibid.*, vol. i. 1872, p. 102.

The results obtained with this apparatus, when worked with gas from separate producers, were excellent as to quality of produce and economical in fuel, and there seems to be no reason why it should not be employed in the manufacture of "open-hearth" steel.

Various interesting applications of the blow-pipe principle to furnaces

FIG. 576.



have been proposed and carried out in recent years, not merely on a small scale by Mr. T. Fletcher, of Warrington, but also as applied to furnaces for boiler-making, welding, plate, and rivet heating, glazing pottery, and smithing operations.* The following illustrations also show proposed methods

* See "Engineering," Nov. 7, 1879; also E. Crowe in "Jour. Soc. Chem. Ind.," vol. i. 1882, pp. 54, 55.

of applying this principle to the melting of pig-iron for foundry use, and for the first stage of steel making by the "open-hearth" process.

FIG. 577.

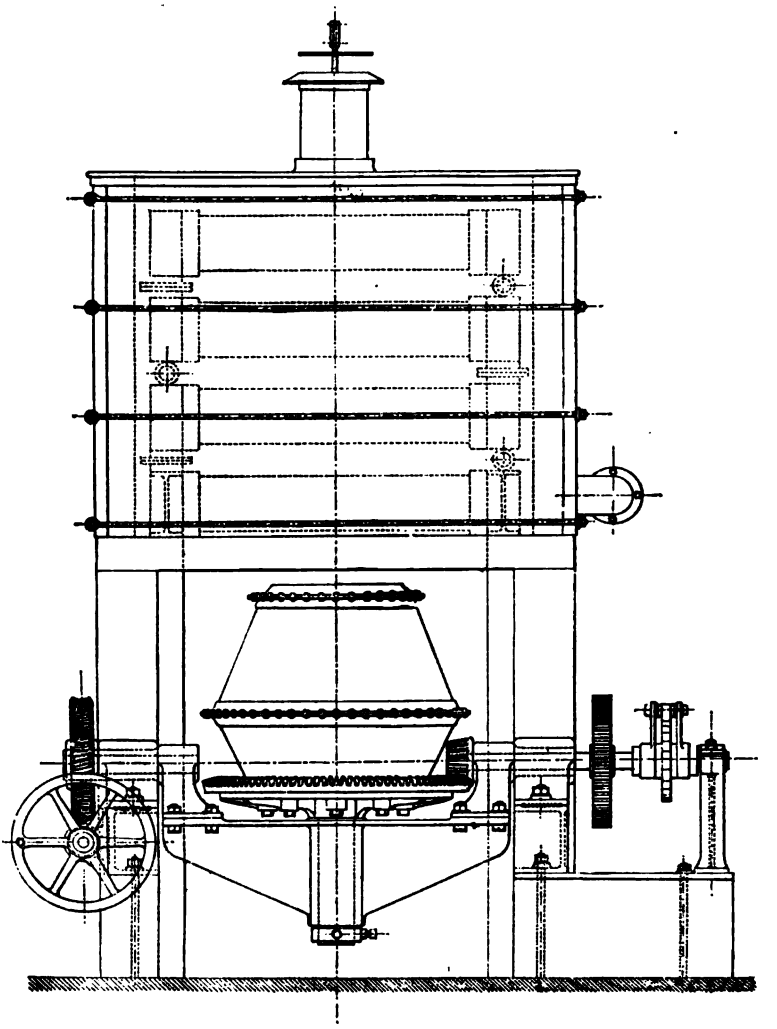


Fig. 578 shows a "gas cupola" designed by Mr. Alfred Wilson* for the purpose of melting pig-iron as fast as an ordinary cupola, but with about 2 cwt. small coal or dross per ton of iron (instead of coke), the fuel being used in a gas-producer. The gas flue is shown shaded black, and two or more blow-pipes for air cross this flue and cause an intense flame to extend across the melting chamber. The pig-iron, without fuel, but with some limestone to flux the sand on the pigs, is stacked from the bed of the melting chamber and up the vertical chamber, and may be charged into this latter from the upper platform. The stack of iron partly absorbs the heat of the gases of combustion, and the remaining heat is communicated to the air-

* "Proc. Cleveland Inst. Engineers," June 9, 1879, p. 236.

blast on its passage through the iron pipes in the two vertical chambers behind the melting one.

Fig. 579 is another arrangement proposed for the same operation,* *D* being the gas flue, *E* the air blast pipe, *B* the melting hearth, and *C* the

Fig. 578.

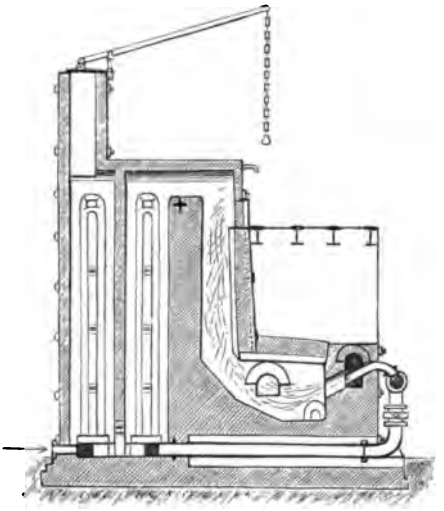
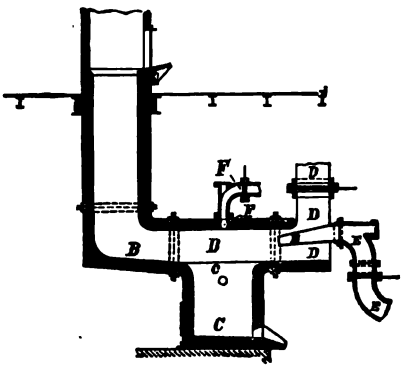


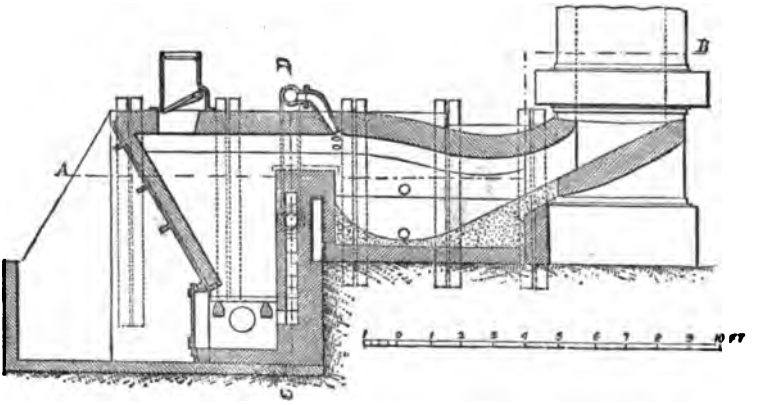
Fig. 579.



crucible or chamber for collecting the melted iron and from which it is tapped. An auxiliary stream of air can be admitted at *F*, if necessary. The pig-iron is charged into the vertical chamber above *B* from the upper platform.

Figs. 580, 581, 582, 583, are illustrations of two forms of gas cupola

Fig. 580.

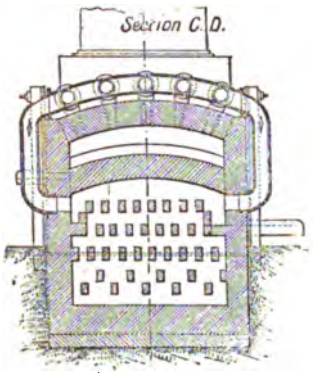


furnaces proposed by Mr. James Riley.† Figs. 580 and 581 show the fireplace or gas generator, and the furnace body of a rectangular form in plan. In Figs. 582 and 583 the furnace is circular in plan, with a gas generator also circular in horizontal section. "In both cases, the gas generator has a

* "Jour. Soc. Chem. Ind.," vol. 1882. pp. 410, 411.
† "Jour. Iron and Steel Inst.," vol. ii. 1885.

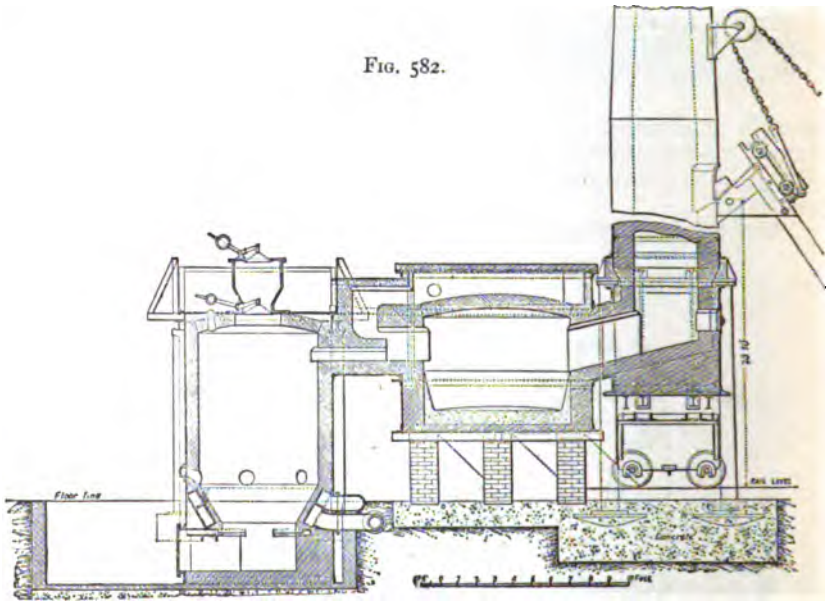
closed grate, and is dependent on forced blast—obtained from an ordinary blower—for supporting combustion in the production of gas from the coal, which is charged in at the top in the customary manner. In like manner, the air for supporting combustion in the body of the furnace is obtained from the blower, and in Figs. 580 and 581 is passed through the pipes or nozzles placed transversely across the body of the furnace almost directly over the bridge which separates generator and furnace. These pipes are inclined so as to direct the flame down on to the bath of metal in the hearth of the furnace. In this design, the air for combustion is heated in the passages in the back wall of the generator through which it is sent to the nozzles referred to.

Fig. 581.



"In Figs. 582 and 583 the air for combustion passes twice round the hearth of the generator, in the pipes shown in Fig. 582, thence to the crown of the furnace body, whence—being thoroughly heated—it emerges by the air-port directly over the gas-port leading into the furnace and to the cupola."

Fig. 582.



Repeated trials of these furnaces showed that an average of 1.44 cwt. of coal per ton of metal charged into the cupola was the consumption in continuous working. Besides this, both carbon and silicon could be reduced in quantity in the iron melted.

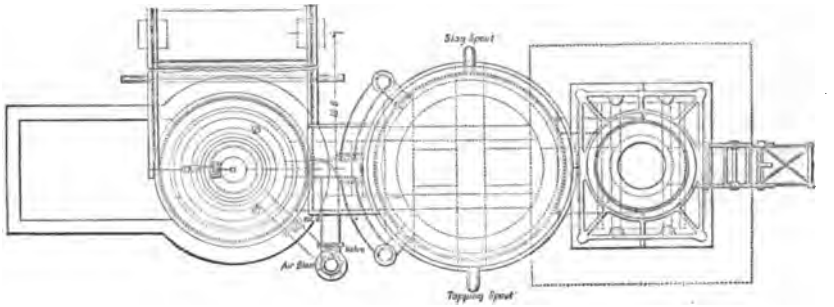
By far the most important gas-furnace which has been introduced is the well-known Siemens furnace* with reversing regenerators. It combines the best features of a gas-furnace with the most complete and perfect method of conservation of the heat. It is, as has been remarked by Dr. Percy,

* *Dingl. Polyt. Jour.*, vol. ccxxvi. p. 162; "Jour. Chem. Soc.," 1868 and 1873; "Brit. Assoc. Reports," 1868 and 1873.

"the most highly organized result in the process of regenerative-furnace evolution."

Introduced into Britain about the year 1859 or 1860, it has been of great practical value, as a means of education in the proper use of fuel, no

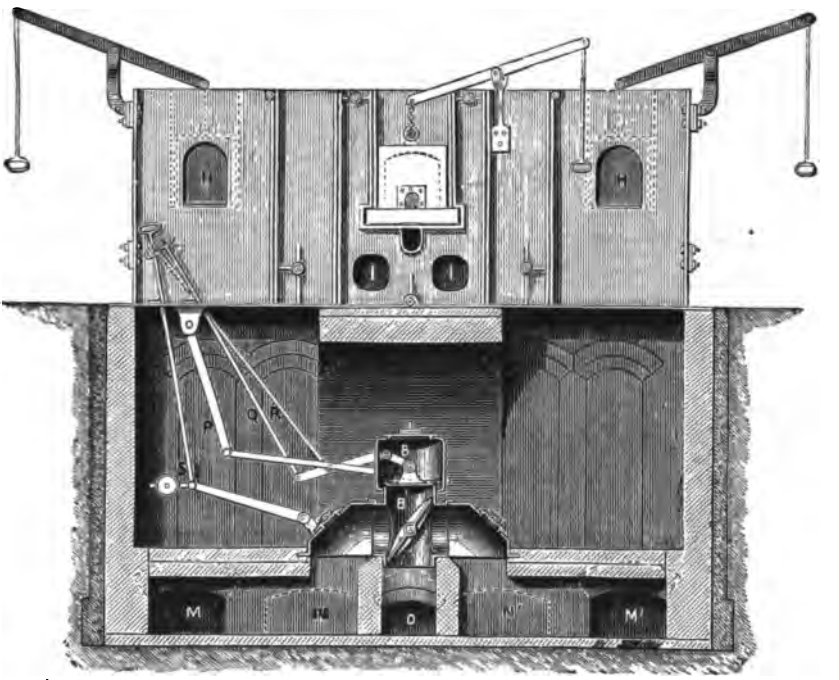
Fig. 583.



less than it has been successful in improving and rendering economical many branches of manufacture.

From Mr. Frederick Siemens' patent specification of 1856 (No. 2,861), it is evident that the furnace was at first designed in view of the use of solid fuel in "one or more fire-places." Very soon, however, the advantages

Fig. 584.



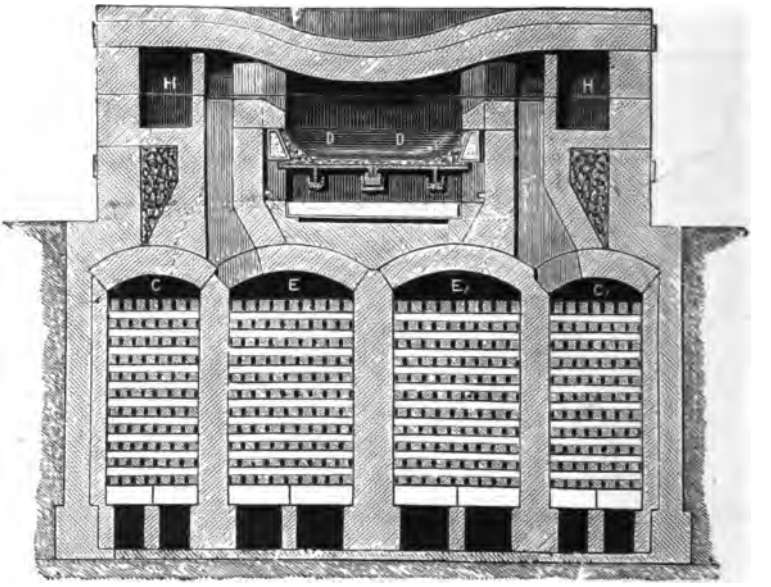
of gaseous fuel became apparent to the Messrs. Siemens, and the separate gas-producer which has already been referred to (see page 254 *ante*) was added as an essential part of their system.

The form of the furnace varies according to the process to which it is applied, but Figs. 584 and 585 illustrate the general features which are

common to all forms. Fig. 584 shows a section through the reversing valves and flues (M and M′ leading to regenerator chambers and O to chimney), which are placed under the working platform in front of the furnace. Fig. 585 is a section through the centre (longitudinally) of the furnace, this line giving also a cross section of the regenerators below. The form of furnace shown is that of a puddling furnace introduced many years ago by the late Sir William Siemens, D being the bed of the furnace, and C, C′, E, E′, the regenerator chambers for gas and air respectively.

The furnace proper stands above four arched brick chambers, and has ports or passages at each end from a pair of these chambers for the admission of the gas and air, or on reversal of the currents for the exit of the hot products of combustion. The regenerator chambers are nearly filled with fire-bricks stacked regularly, without fire-clay, to form an open fret-work. The smaller chamber on the incoming side serves to heat the producer gas

Fig. 585.



on its way into the furnace, and the larger one the air. On the chimney side of the furnace, the hot gases go at will through both chambers simultaneously, the direction of the currents of gas and air and of waste gases being regulated by means of the reversing valves.

Attempts have been made to lessen the cost of construction of these furnaces and to give increased facility for carrying out examination and repair by arranging the regenerators in other positions. C. Wittenström,* in some furnaces erected in Sweden, placed the regenerators upon pillar supports above the roof of the furnace, and more recently Messrs. F. W. Dick and James Riley† have built furnaces with the regenerators clear of the ends of the furnaces and very little below the ground level. Both of these plans have had a measure of success in practice, and they serve to show what may be done when circumstances render it difficult or unadvisable

* "Min. Proc. Inst. C.E.," vol. xli. p. 302, from *Oest. Zeit. für Berg- u. Hüttenwesen*, Feb. 22, 1875.

† "Jour. Iron and Steel Inst.," vol. ii. 1884, p. 434, &c.

to build the regenerators under ground. The underground position is, however, the most suitable for the action of the regenerators both in absorbing heat from the outgoing gases (which are made to descend and thus to fill the chambers and travel slowly) and in imparting heat to the incoming gases (which move upwards and fill the chambers in accordance with their increase of volume as they become heated) with the least danger of having air drawn into the chambers from the outside. In Messrs. Dick and Riley's arrangement of regenerator chambers air is excluded by having the chambers encased in wrought-iron plates, as is done with regenerative hot-blast stoves.

During the course of years, the forms of furnaces have undergone considerable modification as the result of experience. Formerly, roofs were built so low, with the object of securing contact of the flame with the surfaces to be heated or of throwing the flame down on to the furnace bed and materials thereon, that in effect the flame was almost stifled. Great quantities of smoke were produced as the result of imperfect combustion, and it was no uncommon thing to see the imperfectly consumed gases burning with flame at the top of the chimney. As a better understanding of the processes involved in combustion has spread, the larger space necessary for proper combustion has been provided, with consequent beneficial results. This gradual improvement is evident from a comparison of the various combustion chambers provided in steam boilers (especially in marine boilers) during the development of steam navigation, and, as to metallurgical furnaces, testimony to the same effect is on record from Mr. Hardisty,* of the celebrated Elswick Works, Mr. Wailes,† Mr. Dick,‡ of the Steel Company of Scotland's Works, and the late Mr. W. Gorman.§ Mr. Dick has also referred to the Gratz furnace described in "Engineering"‖ as illustrating the same point.

That the practice of the Messrs. Siemens took the same course is evident from a comparison of Fig. 585 with the furnace drawings forming Plate 2 of Dr. Percy's volume on Fuel,¶ the originals from which that Plate was drawn having been supplied by Mr. C. W. Siemens. The sectional elevation on Dr. Percy's Plate shows a high roof and straight ports for gas and air directing the flame horizontally across the furnace.

In 1884, however, Mr. Frederick Siemens** claimed to have discovered that the proper heating in furnaces is due entirely to radiation, as distinguished from flame contact, and that to ensure the suitable condition for this effect furnaces should be built with spacious combustion chambers so that there should be unobstructed space for the free development of flame, which should be secured from contact with walls, roof or bed.

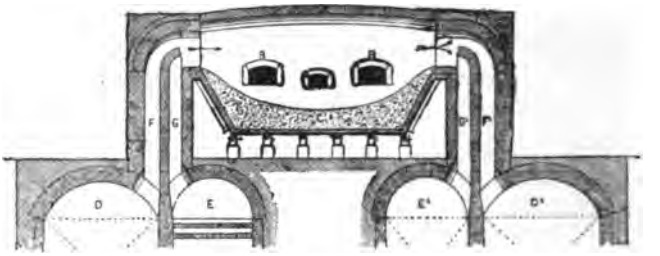
The following figures amongst others were used by Mr. Siemens to illustrate furnaces constructed according to the improved plan, Figs. 586 and 587 giving sections of an "open-hearth" steel melting furnace, Figs. 588 and 589 of a heating furnace, Figs. 590 and 591 of a crucible steel melting furnace, and Figs. 592 and 593 the application of this plan to the firing of steam boilers of the Lancashire pattern.

In Figs. 586 to 589, A is the roof, B, B, are the working doors, C is the bed of the furnace upon which materials are melted or heated, D and E are one pair of regenerators, D^1 and E^1 are the other pair. The gas and air are alternately brought into the combustion chamber by the ports F, G, and

* "Jour. Iron and Steel Inst.," vol. i. 1886, p. 126. † *Ibid.*, vol. ii. 1884, p. 474.
‡ *Ibid.*, vol. ii. 1884, pp. 464, 484.
§ "Proc. Phil. Soc. Glasgow, 1884," vol. xvi. p. 298.
‖ See "Engineering," 1883, vol. xxxv. p. 102.
¶ Percy, "Metallurgy," vol. Fuel, p. 525.
** On a New Method of Heating the Regenerative Gas Furnace: "Jour. Iron and Steel Inst.," vol. ii. 1884, p. 434.

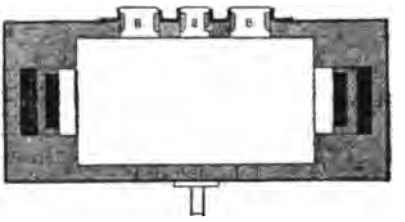
F¹, G¹, therein forming the flame which traverses it from end to end. The arrangement of ports shown in the different furnaces is varied to illustrate

Fig. 586.



different methods of mixing the gas and air, but all unite in directing the flame into the clear space of the combustion chamber, so as to avoid contact with surfaces or materials, at any rate in the first instance.

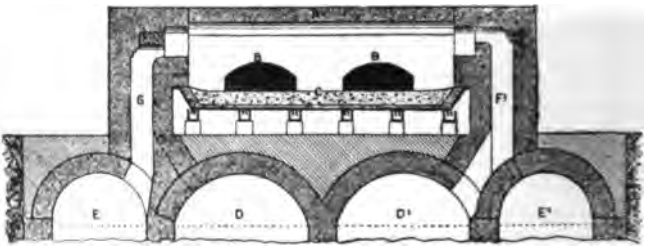
Fig. 587.



Mr. Siemens' theory of "heating by radiation only" was accompanied by some speculations* as to the character of flame, the cause and nature of motion of its particles, and also by some ingenious considerations as to the effect of surfaces in limiting dissociation temperatures †

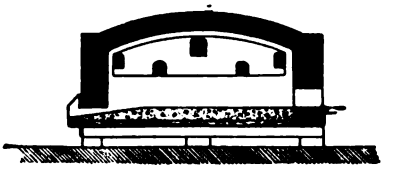
Despite the ingenuity of Mr. Siemens' ideas, it would be extremely difficult, perhaps impossible, to incontrovertibly establish his radiation theory.

Fig. 588.



For instance, Dr. H. E. Armstrong holds‡ that it "entirely depends on the acceptation of" the theory that "the whole radiant effect of a flame is due to the presence within it of incandescent solid particles," while Mr. Siemens maintains§ that the, so-called, "electrical" theory of flame is the only one which fully accounts for the phenomena of combustion in a manner consistent with his views.

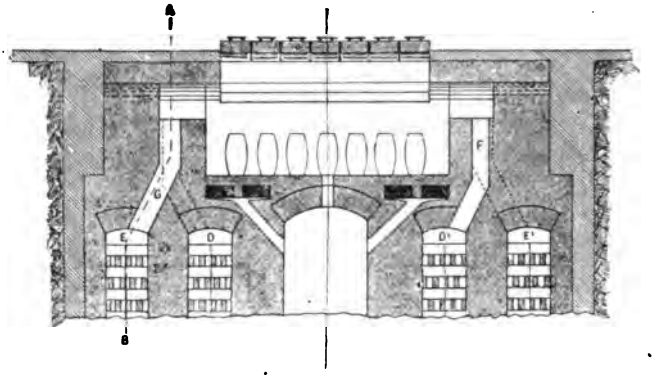
Fig. 589.



* "Jour. Iron and Steel Inst.," vol. ii. 1884, pp. 478-480.
† "Trans. Royal Institution of Great Britain," May 7, 1886.
‡ "Jour. Soc. Chem. Ind.," vol. 1885, p. 623.
§ "Jour. Iron and Steel Inst.," vol. ii. 1884, p. 479.

It seems highly probable that these ideas of the nature of flame are incorrect,* and, therefore, that the foundation for the physical speculations

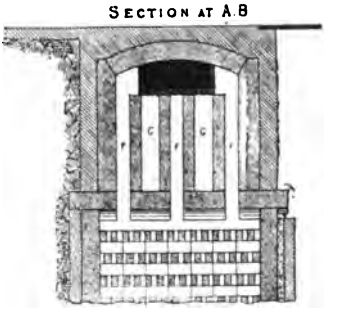
FIG. 590.



connected with the "heating by radiation" theory is bad. Moreover, where the opening for the final exit of the products of combustion from a furnace is at a lower level than the point at which flame enters the furnace, it is impossible (except by means of a very powerful current causing the flame to travel rapidly through the furnace) to prevent the flame completely *filling* the furnace and therefore coming in contact with its roof, sides, and hearth.

FIG. 591.

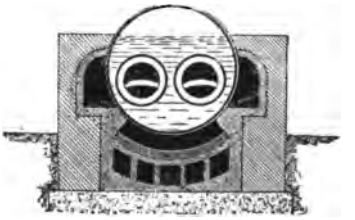
SECTION AT A B



Where the descent to the chimney opening is very small, the flame may be seen creeping along the roof, as this is the part which at the exit has the least depression. In the case, however, of furnaces having regenerator chambers underneath, the very principle which is relied on to cause the hot gases to fill the chambers in descending through them, must act in causing them at an earlier stage to fill the furnace chamber, as this is the first part of their journey downwards to the chimney flue.

There is no doubt that where surfaces that are appreciably colder than a flame are brought into contact with it, their effect is to check the formation of flame because they abstract heat which would otherwise be imparted to the gases in order to bring them up to the ignition temperature. The combustible gas and oxygen are thus imperfectly combined, and the "cutting action" of flame is readily seen to be due partly to mechanical action of the flame and partly to chemical action or oxidation, the surfaces exposed to the flame and gases being greatly softened by the heat and thus easily acted on.

FIG. 592.

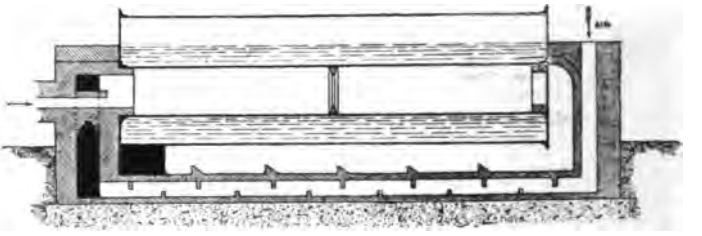


When solids have the temperature of the flame, it has been shown by Tyndall that their introduction into the body of a flame increases its radiant energy, so that a feebly radiating flame such as that of hydrogen or of

* See pp. 365–373 *ante*.

carbonic oxide acquires a considerable amount of radiant energy when a piece of platinum wire or of fire-brick is held in it.

FIG. 593.



This effect is to some extent absent in Mr. Siemens' new furnaces; and as, moreover, his improved results have been obtained in these furnaces,* as far as is known, with ordinary producer gas yielding a flame of low radiating quality, this is another proof that the theory of "heating by radiation only" may be questioned.

The increased economy obtained by Mr. Siemens with his improved form of furnaces is capable of satisfactory explanation apart from the unstable ground of his theory.

If the action of surfaces as tending to promote dissociation be a fact, the partial elimination of dissociation by increased amount of clear space will form an element in the maintenance of a higher temperature of combustion in the furnaces. It is believed, however, by some chemists, that the presence of rough surfaces tends to promote chemical action, and it follows that where the influence of such surfaces operates in furnaces having confined spaces, combustion takes place more readily at a lower temperature, even if imperfectly. Smooth surfaces, or, what is equivalent, eliminating the effect of rough surfaces by distance, tends to produce, therefore, a higher temperature of combustion. Added to this, in the improved furnaces space is provided which is requisite for the thorough admixture of the gases and the spread of inflammation and combustion throughout their whole mass, this being a gradual operation, for several reasons alluded to in the section on "Flame."

Mr. Siemens has himself said in a more recent paper† on this subject, "as flame is nothing but molecular motion of combining gases, this circumstance alone proves the necessity of not interfering with such motion, whilst the moving molecules, although indefinitely small, are so numerous and move so rapidly, that they represent an amount of energy which, acting constantly, must in time destroy any surface or object exposed to it; besides which, the flame has most probably a chemical influence that tends to assist this process of destruction." These remarks are just, and it is no doubt further consideration of the subject on such lines that has induced Mr. Siemens to say of his system in this last paper, that "it is now preferred to describe it under its more general term as heating with free development of flame."

Since the successful introduction of the Siemens furnace, many designs have been proposed and tried with the object of securing economy of fuel and the benefits of gas firing without the expense of building furnaces with regenerators or separate gas-producers. One of these is the Boëtius furnace, patented in Britain in 1865, and successfully used on the Continent for both glass melting and iron heating. This furnace is illustrated in Mr. D. K. Clark's work on "Fuel, its Combustion and Economy" (pp. 268–9, 2nd edition); in "Proceedings Cleveland Inst. of Engineers" (February 9, 1871), and elsewhere.

* "Jour. Iron and Steel Inst.," vol. ii. 1884, pp. 438–440. † *Ibid.*, 1886, p. 693.

Some ingenious forms of furnaces were introduced about the same time in England and Scotland by the late Mr. E. B. Wilson, and will be found described in vols. i. and ii. of the "Practical Mechanics' Journal."

Bicheroux followed somewhat in the line of Boëtius, and his furnace* has been successful both abroad and in England.

A furnace introduced by Mr. Smith-Casson as the Casson-Dormoy† furnace was worked at Round Oak Works and has passed through several modifications which gradually approximated it in design to that of the Bicheroux furnace. Latterly, it has been combined with the Bicheroux design, and is now described as the Casson-Bicheroux‡ system.

Amongst other interesting furnaces, having a gas-producing fire-place attached to each furnace, which must be mentioned, is the so-called "retort" furnace introduced by the late Mr. Price at Woolwich Arsenal. It was fully described by Sir I. Lowthian Bell in "Jour. Iron and Steel Inst.," 1875, p. 455, &c., and results of its working were given§ by him and by the inventor.

A form of reversing regenerator furnace, embodying some improvements in construction, which has been introduced in America by Messrs. W. Swindell & Brothers, of Pittsburg, is illustrated in the "American Manufacturer and Iron World," vol. xli. No. 24; and a series of articles by Mr. Thomas F. Morgan, describing the various forms of furnaces employed for using natural gas, will be found in the same volume of that journal.

The late Mr. William Gorman, at an early date in the application of gaseous fuel, grasped the importance of the subject, and had a clear idea of the main features of the system. Speaking in 1859, he (as Mr. Clark remarks‖), "highly appreciating the superiority of the system of combustion by preliminary conversion of the fuel into gas, foresaw the advantage of the system in the facilities afforded by it for placing the combustion where it would be most effective." "This power," Mr. Gorman said, "of transferring the greater part of the combustion of the coal from the grate to the body of the furnace, together with the complete combustion of the coal gas, promises to be of great use in the manufacture and working of iron."¶

Fig. 594 illustrates the general features of Gorman's "heat-restoring furnace," as introduced in 1870. Various improvements in details were added subsequently, some of these having been (up to the year 1881) made the subjects of patents by Mr. Gorman.

"The furnace, with its gas-producer and heat-restorer, occupies about the same space, and is arranged and worked in the same way as an ordinary furnace; having, in addition to the usual damper, valves for admitting, regulating, or shutting off the air supplied for combustion. The gas-producer occupies the same place as the grate in ordinary furnaces, and only differs in being deeper so as to provide at all times a thickness of over 2 feet of fuel on the grate bars."

When the gas from the coal leaves the producer, carrying with it the heat generated there, it is supplied with air for its complete combustion, which mixes with the gas in a small chamber at the bridge, the air being divided into jets to ensure complete admixture, the whole being afterwards passed through a comparatively small orifice to bring the air and gases into intimate union before they are passed into the heating chamber of the

* See D. K. Clark, *op cit.*, pp. 270, 271; *Revue Universelle des Mines*, tome i. 1877, p. 205; "Jour. Iron and Steel Inst.," vol. ii. 1882, p. 760, vol. i. 1884, p. 83; "The Engineer," Aug. 3, 1883; *Dingl. Polyt. Jour.*, vol. ccxxvi. p. 160.

† "Jour. Iron and Steel Inst.," 1876, p. 109; D. K. Clark, *op. cit.*, pp. 274, 275.

‡ See "Jour. Iron and Steel Inst.," vol. i. 1884, p. 60.

§ See also D. K. Clark, *op. cit.*, pp. 276–284. ‖ *Op. cit.*, pp. 238, 332, 333.

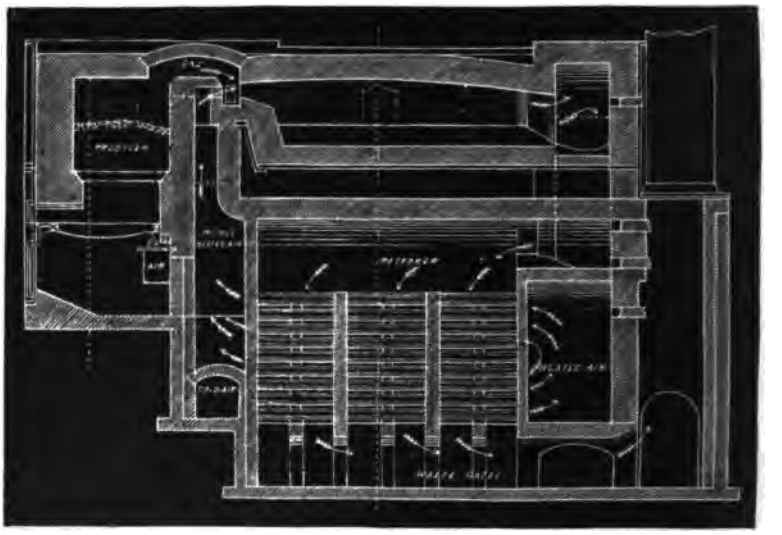
¶ "Trans. Inst. Engineers in Scotland," vol. ii. 1858–59, p. 79; see also *ibid.*, April 18, 1871, p. 245; "Jour. Iron and Steel Inst.," vol. ii. 1871.

furnace. Mr. Gorman remarked* on this point that, "as the gas was not cooled after it left the producer, and the air for combustion was heated to the highest temperature by the escaping gases, an intensely hot flame was projected horizontally into the furnace between the roof and the materials on the bottom or hearth, by which means combustion was effected without the flame impinging on the brickwork of the furnace or on the material which was being heated."

The drawing of the furnace shows that "the roof rises upwards from the jet of flame, and that it is not inclined so as to direct the flame down towards the bottom or hearth, but that the flame has free scope for complete combustion."

The "restorer" is a chamber placed usually under the ground line and containing a number of fire-clay pipes open at each end, the ends of the pipes being supported or carried by thin walls or partitions. The waste gases pass vertically downwards through the chamber in which these pipes are placed horizontally and heat the tubes from their outside surfaces. The air for combustion enters the end space at the bottom, passes through the

FIG. 594.



pipes to the space at the other end, rising to a higher series of pipes and re-crossing till it arrives at the top of the chamber; the effect being an upward current of air meeting a downward current of heated gases with only the thickness of the fire-clay tube between them, the current of air inside preventing the destruction of the tube by the high temperature outside. The incoming cold air thus meets the waste gases when about to escape to the chimney, and extracts the remaining heat, whilst the hottest gases impinge on the pipes which contain the air already gradually heated up in ascending, and thus raise it to a still higher temperature.

In advocating this form of heat-restorer and system of working, Mr. Gorman pointed out that it was not liable to the objection which he considered was attached to the Siemens regenerator system—viz., that in heating coal gases up to and above a red heat they deposit solid carbon. He argued that this takes place in the Siemens regenerator, and that on the reversal of the currents the carbon deposited on the brickwork of the regenerator is converted into carbonic oxide by reducing the carbonic acid

* "Proc. Phil. Soc. Glasgow," vol. xvi. p. 298.

in the hot products of combustion. "This chemical action," he said, "lowers the temperature of the escaping gases so as to indicate that nearly all the heat of the fuel has been expended in the furnace, whilst in reality a large part of the most valuable heating power of the coal does not get the length of the furnace, the carbonaceous gases being partly condensed by

Fig. 595.

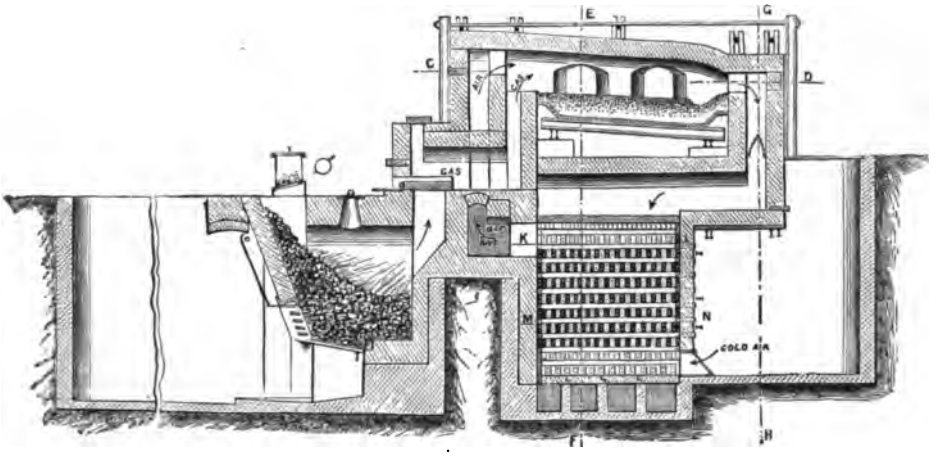


Fig. 596.

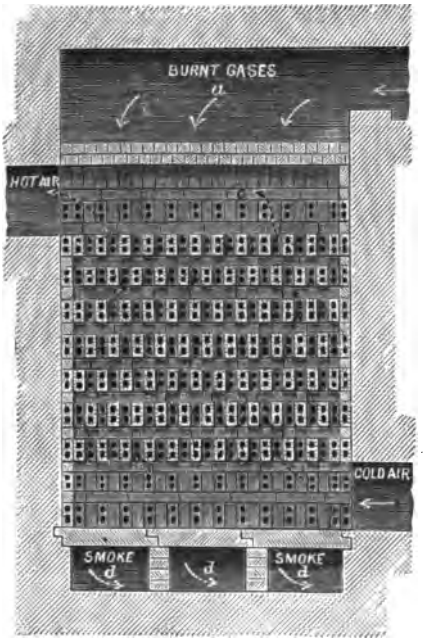
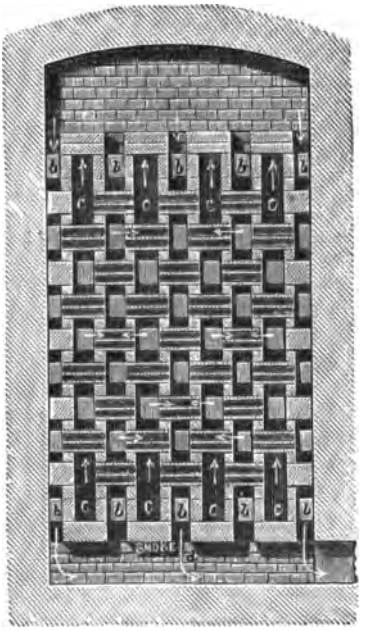


Fig. 597.



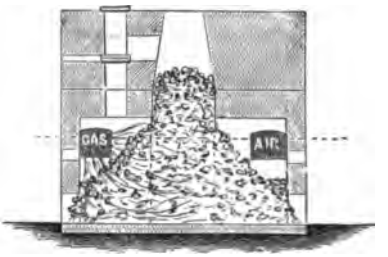
cooling (in the Siemens cooling-tube) and partly deposited by heat in the regenerator on their way to the furnace."

It is probable, however, that Mr. Gorman over-estimated the loss which might arise from deposition of carbon in the regenerators. The action is known to take place to an appreciable extent when illuminating gas or gas

rich in hydrocarbons is heated, and would thus militate against the employment of a richer gas in regenerative furnaces of the Siemens type, unless the air only were heated in the regenerators. As ordinarily worked, however, the Siemens furnaces use a producer-gas which contains scarcely any hydrocarbons other than marsh gas, and, therefore, the decomposition referred to cannot take place to any extent worth noticing.

Gorman's furnace worked with great economy, using only about 3½ cwt. of coal per ton of iron in mill furnaces, and was fairly durable, the only serious difficulty having been occasioned by the fire-brick pipes of the restorer cracking under the action of rapid expansion or contraction, when the furnace was being heated up or cooled.

Fig. 598.



Ponsard's furnace (Figs. 595, 596, 597) is of the same class as Gorman's, having a gas-producer attached to the furnace and a recuperator for intercepting waste heat and conveying it to the air supply above.

Fig. 595 illustrates a sectional elevation of furnace, "gazogene" or producer, and recuperator; the producer shown being of the ordinary Siemens form with sloping grate fed with air at atmospheric temperature. M. Ponsard also introduced a form of "gazogene" without grate, which was worked with air heated in the recuperator. Fig. 598 represents a section of this "superheated gazogene," showing the openings for charging fuel from above and for withdrawing slag and ashes below. The air heated to from 1500° to 1800° F. traverses the mass of fuel, the gas escaping at a high temperature into the furnace.

The gain in heat utilized by this system is shown as follows:—

Percentage Losses of Heat with Different Kinds of Coal.	Metallurgical Furnace with Ordinary Produce.					With Superheated Producer.				
	Coal No 1.	No. 2.	No. 3.	No. 4.	No. 5.	Coal No. 1.	No. 2.	No. 3.	No. 4.	No. 5.
By production of gas . . .	10.9	9.8	8.35	7.8	5.7	16.2	14.8	14.35	12.0	9.0
„ the waste gases . . .	31.4	29 0	28.2	27.3	25.6	18.3	18.0	18.50	18.0	18.0
Total loss	42.3	38.8	36.55	35.1	31.3	34.5	32.8	32.85	30.0	27.0
Heat utilized (by difference) . .	57.7	61.2	63.45	64.9	68.7	65.5	67.2	67.15	70.0	73.0

The Ponsard recuperator is built of fire-brick, the channels or passages for air and waste gases being formed by vertical diaphragms and perforated bricks. The hot waste gases occupy one set of vertical passages *b* (Fig. 597), through which they descend to the smoke flue, whilst the air ascends by the other set, *c*. Each set of vertical passages is alternately coupled together by perforated bricks, which add to the heating surface and serve to break up the currents, acting as baffle plates. The construction of this recuperator may be understood by reference to the longitudinal and transverse sections given in Figs. 596 and 597.

Several interesting examples of the Ponsard system were carried out on the Continent, and their results are recorded in an exhaustive examination of the system by M. Sylvian Périssé* (Note sur le Four à Gaz avec Récupérateur de Chaleur, Système Ponsard, in *Mém. et Compt. Rend. des Travaux de la Soc. des Ingén. Civils*, 1874, p. 752, and 1875, p. 292), who gives the

* See also D. K. Clark, "Fuel, &c.," p. 317, &c.

following comparison with the Siemens system as regards utilization of heat :—

Utilization of Heat with the Following Systems.	Different Kinds of Coal.				
	No. 1.	No. 2.	No. 3.	No. 4.	No. 5.
Ponsard furnace, with ordinary producer .	57.7	61.0	62.7	63.5	66.4
,, ,, superheated . . .	65.5	67.2	67.1	70.0	73.0
Siemens furnace	52.8	56.0	57.7	59.5	62.8

The latest development in this country of the gas furnace with continuous regeneration and gas-producer attached to the furnace, is that of Mr. F. Radcliffe, superintendent of the forge of the Royal Gun Factory at Woolwich.

FIG. 599.

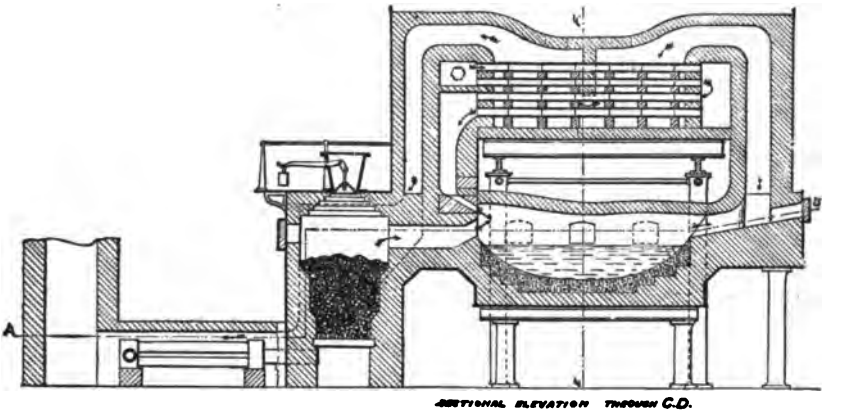
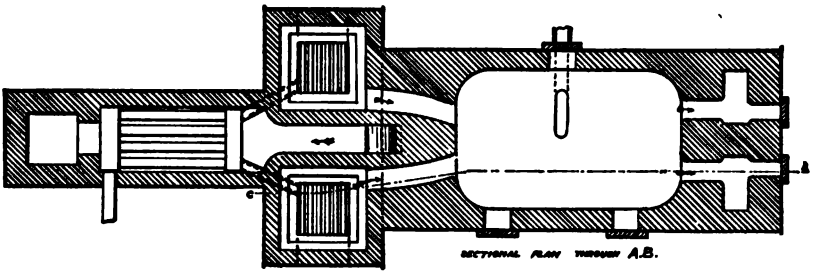


FIG. 600.

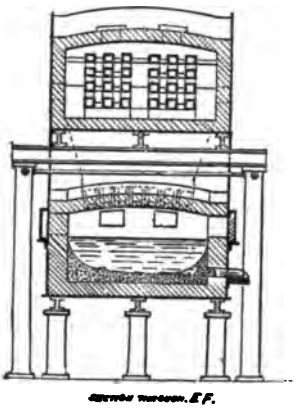


Figs. 599, 600, 601 illustrate this system, which has been designed to avoid the expense of constructing regenerator chambers or passages below the surface, and to combine producer, regenerator and furnace in one structure. The illustrations show an open-hearth steel-melting furnace, Fig. 599 being a vertical section through the combustion chamber, regenerator and gas producer; Fig. 600 is a sectional plan on the line *AB* of Fig. 599; and Fig. 601 is a cross section through the line *EF* of Fig. 599. The producers have grate bars and closed ashpits, as they are worked by a forced air supply, a pressure equal to 6 inches of water column being used in supplying this part of the apparatus. Half that pressure of air is found sufficient for sending the air supply for combustion in the furnace through the regenerator passages.

Before the air supply is allowed to pass into the gas producers, it is heated, in cast-iron pipes, by means of the waste heat of the escaping gases,

to between 700° and 800° F. The gas thus produced has a comparatively high temperature, and passes at once into the furnace.

FIG. 601.



The regenerator is placed over the furnace, but is carried, by pillars and iron beams, clear of it, to allow of independent repair. It is constructed of fire-brick, the air passing to and fro through pipes or small channels, whilst the hot waste gases first descend and then ascend among these pipes in traversing externally their entire length. This construction has the merit of simplicity and of avoiding the necessity for numerous valves, the only valves required being those for regulating the air-supply to the gas producers and to the regenerator.

The first furnace of this design which was erected for steel melting was tried at Woolwich during 1885. It was of a capacity for 6-ton charges, and worked for many months without cessation, the average consumption of fuel being 8.5 cwts. per ton of ingots produced. After undergoing some repairs, it was started on January 9, 1886, and worked without stopping until March 31, making 124 charges as follows:—

	Tons.	cwts.	qrs.
Total weight of metal charged	822	10	0
" " ingots produced . . .	786	12	3
" " fuel consumed	339	6	0
" " skulls and scrap . . .	11	16	3

The fuel includes 11 tons used in heating the furnace preparatory to working the first charge.

The results obtained with this furnace were so satisfactory that a 10-ton furnace was built and started during 1886, the results of the working of which, as checked by the Store Department at Woolwich, were extremely good, showing, as was to be expected, a superior economy of fuel to the smaller furnace.

The following statement gives the results of four consecutive weeks' working of the 10-ton furnace:—

—	Week ending June 26, 1886.	Week ending July 3, 1886.	Week ending July 10, 1886.	Week ending July 17, 1886.	Totals Four Weeks ending July 17, 1886.
	tons cwts. qrs.	tons cwts. qrs.	tons cwts. qrs.	tons cwts. qrs.	tons cwts. qrs.
Total weight of charges	101 10 0	78 10 0	96 5 0	97 0 0	373 5 0
Weight of ingots made	96 15 0	75 6 3	91 9 3	91 14 0	355 5 2
Skull and scrap . .	1 3 2	1 0 3	1 16 1	1 8 0	5 8 2
Coal consumed . .	29 5 0	24 0 0	26 17 0	27 5 0	107 7 0
	cwts.	cwts.	cwts.	cwts.	Average. cwts.
Fuel per ton of ingot .	6.04	6 37	5.87	5 94	6.04

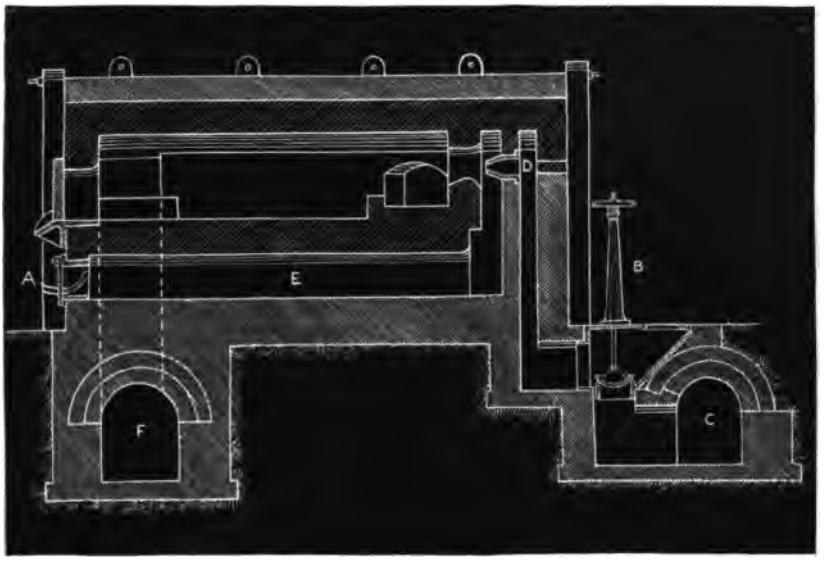
The coal consumed in maintaining the heat in the furnace from Saturday till Monday is included in this statement.

This system has, since then, been developed in the Royal Gun Factory, and will probably be extended to other works.

The use of gas-producing fireplaces attached to furnaces has been developed on the Continent, and to some extent in Britain, in connection with the firing of the furnaces for heating retorts in gas-works. Several of

these plans are described at pp. 611–617. Mr. Hartmann, and Mr. Haupt,* of Brieg, also introduced some ingenious forms of such gas furnaces

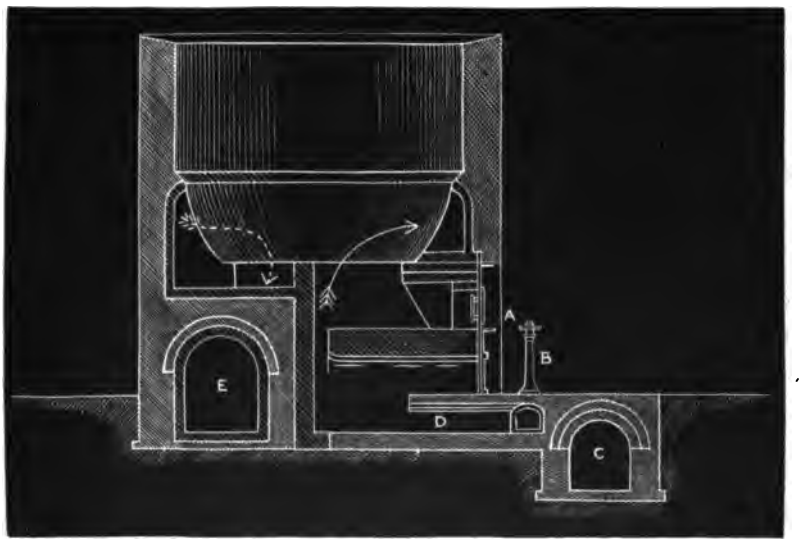
FIG. 602.



as applied to steam boilers, and the latter obtained remarkably good results in comparative trials with a hand-fired boiler (see p. 556).

Fig. 602 illustrates a gas annealing furnace designed and introduced by

FIG. 603.



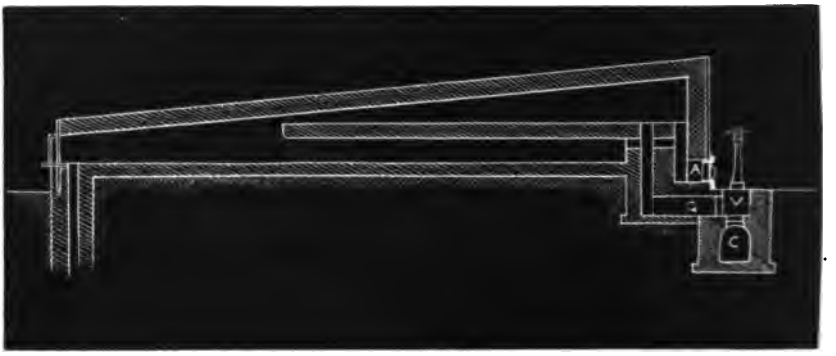
Mr. A. Wilson of Stafford, to work in connection with a separate gas producer. A is the air inlet or valve, B the gas valve, C the gas flue, D the

* See *Chemiker Zeitung*. 1880. p. 290; "Engineering," Jan. 2, 1880.

passages for entrance of gas into the mixing chamber, where it meets the air which has been slightly heated in the passage, E, which runs under the furnace bed. F is the chimney flue.

An application of gas firing to evaporating is shown in Fig. 603, which illustrates a form of gas furnace for brewers' coppers, designed by Mr. B. Dawson, of Malvern, and carried out by him successfully in several breweries in England. A is the air inlet, B the gas valve, C the gas flue from producer, D the flue for gas after passing through the regulating valve B. The arrows

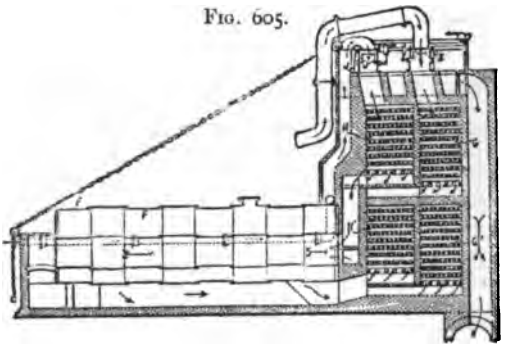
FIG. 604.



show the course of the flame and hot gases round the bottom of the copper and down to the chimney flue E.

Fig. 604 is a design also by Mr. Dawson, and, like the previous one, uses air of atmospheric temperature, as a low heat is all that is required in them. This figure shows a gas muffle furnace for heating copper, and is of simple construction.

FIG. 605.



A method of applying regenerators of the Siemens reversing type to boiler furnaces, which has been designed by Mr. Hill, is shown in Fig. 605.

It would be impossible to illustrate or describe all the possible applications of gas to furnaces, because they are as numerous as the applications of fuel, and it may safely be said that, as intelligence spreads, no other system of utilizing solid fuel will survive.

The Practical Effect of Fuel.—It has already been repeatedly mentioned, that the effect obtained by fuel in practice is very much below what it should be according to theory. The causes of this are partly fortuitous; partly, however, they pertain to the nature of the process, and are consequently unavoidable. The maintenance of a draught in the chimney, to which a portion of the heat evolved is always sacrificed, is one of the more important sources of loss.

By reference to a former page, it will be seen that 1 lb. of dry wood requires on an average 5.94, or, in round numbers, 6 lbs. of air of 0° (= 148 cubic feet) for perfect combustion: suppose this air to escape with a temperature of 150° C. into the chimney, the quantity of heat then contained

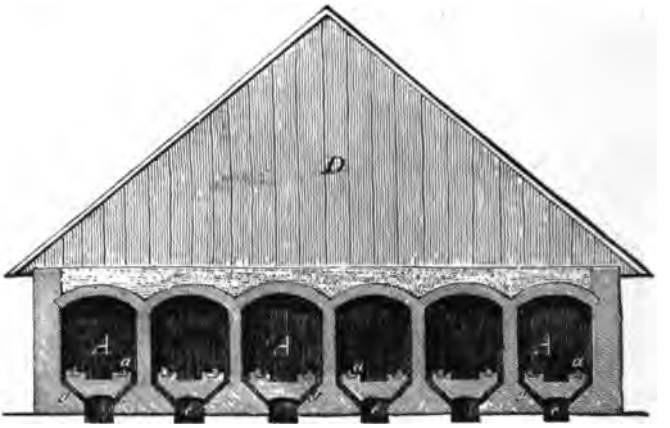
in it will be as great as that contained (in 1 lb. of air at $\times 150° = 900°$ or) in 9 lbs. of air at 100°, and consequently in $\frac{9}{4.21} = 2.1$ lbs. of water at 100° C. According to Schödler and Petersen, 1 lb. of dry wood will heat on an average 40.6 lbs. of water to 100°: the action of the chimney, therefore, causes a loss of $\frac{2.1}{40.6} = 0.052$, or 5.2 per cent., which loss increases with the temperature of the escaping air.

A portion of the fuel is also prevented from combining with oxygen and evolving heat by the lowness of the temperature in the immediate vicinity of the sides of the fireplace, and at least twice as much air is usually admitted as is theoretically required; this also diminishes the temperature, whilst the occasional obstructions to the proper access of air through the grate bars farther lessen the efficacy of the fuel. These impediments to perfect combustion cause a portion of the fuel to be converted into volatile or non-volatile products, which are mechanically carried away by the draught to the remoter parts of the chimney, where they pass off as *smoke*. The smoke, when it consists partially of unburned hydrocarbons, mixed with carbonic oxide, is still capable of uniting with oxygen, and of evolving a quantity of heat equivalent to that portion which is lost. The combustion in the fireplace is therefore a partial process of dry distillation: instead of the vapour of water, carbonic acid and nitrogen being the sole products, these gases constantly pass off mixed with smoke, which partly collects as *soot*. The smoke-consuming arrangements in stoves affect to burn the smoke by bringing it into contact with a stream of hot air. The condensable portions of the smoke, as well as the water formed during combustion, absorb heat in being converted into vapour, and this heat is, for the most part, lost. The loss occasioned by the hygroscopic water, from which fuel is seldom free, is still greater. In the first place it diminishes the weight of the combustible—1 cwt. of wood, for instance, only containing 80 lbs. of actual fuel—and secondly, the water absorbs a large amount of heat in being converted into vapour. For this reason, Rumford's experiments (with common wood) give a smaller result than those calculated from the analyses (with dry wood), although the heat of the vaporized hygroscopic water is not lost in the calorimeter, as it is in practice, being in the former case condensed again into water. Wood, in the ordinary air-dried condition, contains about $\frac{1}{5}$th water, and only $\frac{4}{5}$ths of actual fuel; of the 40.6 lbs. of water which 1 lb. of dry wood heats to 100°, $\frac{40.6}{5}$ $= 8.1$ lbs. are left cold; besides, every $\frac{1}{5}$th lb. absorbs as much heat as corresponds with $\frac{1}{5}\text{th} \times 5.5 = 1.1$ lb. of water at 100°. Altogether, therefore, the moisture in the wood causes a loss of heat $= \frac{8.1 + 1.1}{40.6} = 22\frac{1}{2}$ per cent.

This clearly explains the economy of dry fuel. For domestic purposes, it is generally too costly, and not practicable, to dry the wood by artificial means; while, for certain applications in the arts, dry fuel only can be employed. Fig. 606 represents a section of a drying kiln for fuel, first introduced in the French glass-houses. The whole space covered by a single roof is a long quadrangle, and contains six arched passages *A A A*, 60 feet in length, 6 feet broad, and 5 feet high, which may be viewed as separate stoves, each having its own fire *ccc*. Each fire-place extends below the whole length of the arch *A A*, terminating at both ends in a grate, whence the heat is conducted to the middle of the arch, but also freely escapes along the whole length into the space *A* by the several flues *gg* cut in the sides. These flues are farther apart in the neighbourhood of the grates, but are

more numerous towards the middle, so as to spread the heat more equably. The fires *ccc* are arched over for a short distance above the two grates; farther on, and towards the middle, they are covered with sheet-iron.

FIG. 606.



Above is a railway *aaa*, upon which the iron barrows travel, containing the fuel to be dried. The iron plates prevent the flame from igniting the contents of the barrows, each of which contains about two stacks of wood; there are nine barrows in every arch *A*, and the whole charge is dried in thirty-six hours.

Although water has thus been shown to diminish the effect of fuel, this is not invariably the case under all conditions, and a contrary result appears to be produced when the water is brought into contact with the fuel in the gaseous state. The experiments of Bunsen and Fyfe have shown that red-hot coal and aqueous vapour mutually decompose each other into hydrogen and carbonic oxide (with some carbonic acid), both of which, if sufficient oxygen be present, burn with the production of considerable heat to form water and carbonic acid;* numerous observations showed further, that the additional heat evolved more than compensated for the fuel employed in producing the vapour. If, therefore, sufficient air be present with the vapour to burn the gases which are formed, the vapour will be of service, producing a greater amount of heat and a more lively combustion. The moment, however, that the vapour exceeds the proper proportion, and the supply of air is thus diminished, the temperature rapidly sinks, so that the fire is often totally extinguished. It is probable that in these "observations," which appear to have been calculations, and not experimental results, Messrs. Bunsen and Fyfe did not take into account the heat absorbed or rendered latent in the dissociation of the steam used, or the specific heat of the water-vapour re-formed on the combustion of the hydrogen. Their estimate of the available heat is thus too high.

It may be observed that the *brightness* of the flame produced with steam often leads to the conclusion that it is a hotter flame than it is actually found to be on examination.

A common practice is to place a vessel with water under the grate of

* One part of coal, burning, surrounded by vapour, first to carbonic oxide and then to carbonic acid, heats 78.15 of water to 100°; 0.1666 part of hydrogen is liberated at the same time, which, in burning, heats 39.5 parts more water. The advantage gained, therefore, is $= \frac{78.15}{78.15+39.5} = \frac{1}{3}$, supposing the combustion of coal in aqueous vapour to be attended by the same heating phenomena as in the air.

the furnace, so that the heat radiating downwards may cause evaporation without cost. In steam-engines, a portion of the vapour which has been used may be conducted at once to the fire, instead of being condensed. An addition of water to the fuel causes so great a depression of temperature while the water is being converted into vapour, that the decomposition of the aqueous vapour can no longer be effected, and the practice, which is not unfrequent amongst consumers of coal, is therefore not economical. Practical experiments, instituted by the Frankfort Society for the Improvement of Arts and Manufactures, have also clearly proved the practice to be bad. A moderate moistening of small coal has, however, the advantage of preventing its falling through the grate-bars and creating dust, for it cakes together and becomes more solid by being moistened; it also gives more flame. It is still better to add about $\frac{1}{5}$th of moist clay for the same purpose, which, being disseminated throughout the mass of the coal, affords greater access to the air, and the heat absorbed by the clay, being slowly evolved, acts with more advantage. The experiments made by the Frankfort Society have shown that small coal mixed with clay was even better than small coal alone.

When moist wood is so closely heaped together that the air cannot pass freely through, a change quickly follows, which is accompanied by the almost entire destruction of its combustibility; this change is really originated by minute living organisms. It is well known that the dead wood in the centre of old trees (where moisture, but little air, has access) becomes changed into a white, soft, phosphorescent substance, which, when ignited, burns slowly without flame, like tinder, evolving very little heat. During this mouldering process, the weight of the wood has undergone greater change than the relative proportions of its elements. A specimen contained, for instance, 47 per cent. carbon, and with 6 per cent. hydrogen only 45.3 per cent. oxygen; this greater proportion of hydrogen than in fresh wood would tend to increase the inflammability of the substance if it were not already chemically combined to form water, a supposition fully borne out by the properties of the substance. Wood thus changed is said to have undergone *dry rot*.

The heating value of combustibles obtained by careful experiment and calculation is of great importance as a control in estimating the beneficial practical application of fuel, and an indication of what may be obtained. The difficulties in the way of perfect combustion, however, are so numerous and varied in their source in the different methods of employing fuel, that no estimation of its value for any particular object can be accurately determined by one method. It has consequently been found necessary to ascertain by direct experiment the relative value of combustibles in the various kinds of grates, fire-places, boiler-fires, &c., which they are intended to supply.

With reference to the warming of dwellings, it was found in a series of experiments—in which the external temperature varied from $+6.8°$ (44° F.) to $-6.2°$ (21° F.), and the air of the room had a mean temperature of 15° to 19° C. (59° to 66° F.), while the smoke escaped by the chimney at a temperature of 75° to 100° C. (167° to 212° F.)—that 100 lbs. of air-dried cleft beech wood effect as much as 48 lbs. of pit-coal, 40 (the smoke being cooled as much as possible) to 60 lbs. of mixed small coal moistened with $\frac{1}{17}$th of water, 44 lbs. of bituminous small coal with $\frac{1}{17}$th water, 37 lbs. of small coal with $\frac{1}{17}$th water and $\frac{1}{5}$th clay, and 38 lbs. of small coal with $\frac{1}{5}$th water and $\frac{1}{5}$th clay. The observed temperature of the air was a mean, existing at an equal distance from the floor and ceiling of the room. The observations prove, that the temperature of a room, after equilibrium has once been established, is highest at the top, and increases for equal distances from the

[*continued on p.* 702.]

GENERAL SYNOPTICAL TABLE OF THE CHARACTER AND

	Designation of Coal.		Specific Gravity.	Weight per Cubic Foot, calculated from Specific Gravity.	Weight per Cubic Foot, by Experiment.	Ratio of Actual to Calculated Weight.	Cubic Feet of Space required to stow a Ton.	Volatile Combustible Matter in 100 Parts.	Fixed Carbon, in 100 Parts.	Earthy Matter, in 100 Parts.
Anthracite	Beaver Meadow, slope No. 3	Pa.	1.610	100.645	54.93	0.546	40.78	2.38	88.94	7.110
	Beaver Meadow, slope No. 5	Pa.	1.551	96.930	56.19	0.580	39.86	2.66	91.47	5.150
	Forest Improvement	Pa.	1.477	92.310	53.66	0.581	41.75	3.07	90.75	4.410
	Peach Mountain	Pa.	1.464	91.510	53.79	0.588	41.64	2.96	89.02	0.130
	Lehigh	Pa.	1.590	99.390	55.32	0.557	40.50	5.28	89.15	5.560
	Lackawanna	Pa.	1.421	88.840	48.89	0.550	45.82	3.91	87.74	6.350
	Lyken's Valley	Pa.	1.389	86.820	48.56	0.559	46.13	6.88	83.84	9.250
	Beaver Meadow (navy yard)	Pa.	—	—	55.08	—	40.65	—	—	8.100
	Natural coke of Virginia	Va.	1.323	82.700	46.64	0.564	48.03	12.44	75.08	11.830
	Coke of Midlothian coal	Va.	—	—	32.70	—	68.50	—	—	16.550
	Coke of Neff's (Cumberland) coal	Va.	—	—	31.57	—	70.95	—	—	13.340
	Mixture, one-fifth Midlothian and four-fifths Beaver Meadow		—	—	54.29	—	41.26	—	—	8.880
	Mixture, one-fifth Cumberland and four-fifths Beaver Meadow		—	—	54.51	—	41.09	—	—	8.180
Free Burning Bituminous	New York and Maryland Mining Company's	Md.	1.431	89.440	53.70	0.600	41.71	12.31	73.50	12.400
	Neff's Cumberland	Md.	1.337	83.280	54.29	0.652	41.26	12.67	74.53	10.340
	Easby's "Coal-in-Store"	Md.	1.307	81.690	53.47	0.655	41.90	14.98	76.26	8.080
	Atkinson and Templeman's	Md.	1.313	82.090	52.92	0.645	42.33	15.53	76.69	7.330
	Easby and Smith's	Md.	1.332	83.260	51.16	0.614	43.78	15.52	74.29	9.300
	Cumberland (navy yard)	Md.	1.414	88.400	53.29	0.603	42.04	14.87	70.85	14.980
	Dauphin and Susquehanna	Pa.	1.443	90.190	50.54	0.560	44.32	13.82	74.24	11.490
	Bloomsburg	Pa.	1.324	82.730	53.05	0.641	42.22	14.78	73.11	10.770
	Lycoming Creek	Pa.	1.388	86.740	55.38	0.638	40.45	13.84	71.53	13.960
	Quin's Run	Pa.	1.331	83.220	50.34	0.605	44.50	17.97	72.79	8.410
	Karthaus	Pa.	1.284	80.220	52.54	0.655	42.63	19.53	73.77	7 000
Bituminous Coking	Cambria County	Pa.	1.407	87.840	53.46	0.608	41.90	20.52	69.37	9.150
	Barr's Deep Run	Va.	1 382	86.410	53.17	0.615	42.13	19.78	67.96	10 470
	Cronch and Snead's	Va.	1.451	90.710	53.59	0.591	41.80	24.38	59.98	14.280
	Midlothian (900 feet shaft)	Va.	1.437	87.500	50.52	0.577	44.34	27.28	61.08	10.470
	Creek Company's coal	Va.	1.319	82.480	46.50	0.564	48.17	32.47	60.30	8 570
	Clover Hill	Va.	1.285	80.360	45.49	0.566	49.25	32.21	56.83	10.130
	Chesterfield Mining Co.'s	Va.	1.289	80.570	45.55	0.565	49.18	32.63	58.79	8.630
	Midlothian (average)	Va.	1.294	80.900	54.04	0.568	41.45	29.86	53.01	14.740
	Tippecanoe	Va.	1.346	84.140	45.10	0.536	49.67	34.54	54.62	9 370
	Midlothian ("new shaft")	Va.	1.325	82.820	47.90	0.581	46.76	35.77	56.40	9.140
	Midlothian (screened)	Va.	1.283	80.210	45.72	0.570	48.99	34.70	54.06	9.660
	Midlothian (navy yard)	Va.	1.390	86.860	54.47	0.627	41.13	29.12	56.11	14.140
Bituminous	Pictou (from New York)	N.S.	1.318	82.350	53.55	0.650	41.83	27.83	56.98	13.390
	Sydney	N.S.	1.338	83.660	47.44	0.567	47.22	23.81	67.57	5.490
	Pictou (Cunard's)	N.S.	1.325	82.830	49.25	0.595	45.48	25.97	60.74	12.510
	Liverpool	Eng.	1.262	78.890	47.88	0.607	46.78	39.96	54.90	4.620
	Newcastle	Eng.	1.257	78.540	50.82	0.647	44.08	35.83	57.00	5.400
	Scotch	Scotland	1.519	94.950	51.09	0.538	43.84	39.19	48.81	9.340
	Pittsburg	Pa.	1.252	78.370	46.81	0.598	47.85	36.76	54.93	7.070
	Cannelton	Ind.	1.273	79 540	47.65	0.599	47.01	33.99	58.44	4.970
	Dry pine wood		—	—	21.01	—	106.62	—	—	0.307

EFFICIENCY OF THE AMERICAN COALS.

Ratio of Fixed to Volatile Combustible Matter.	Total Weight of Coal consumed.	Pounds burned on a Square Foot of Grate per Hour.	Hours required to bring the Boiler to Steady Action.	Cubic Feet of Water evaporated per Hour during Steady Action.	Pounds of Steam to 1 lb. of Coal from Initial Temperature.	Pounds of Steam to 1 lb. of Coal from 212°.	Pounds of Steam furnished by 1 Cubic Foot of Coal.	Total Waste in the State of Ashes and Clinker from 100 of Coal.	Weight of Clinker alone from 100 of Coal.	Average Weight, in lbs., of Unburnt Coke left on the Grate after Each Experiment.	Parts of Lead reduced from Litharge by 1 of Combustible Matter of the Coal.	Steam from 212° from 1 of Combustible Matter.
37.31	3944.5	6.69	3.87	12.57	8.20	9.21	505.5	11.960	1.01	112.4	32.41	10.462
25.36	4250.5	6.27	2.42	10.66	8.76	9 88	556.1	6.740	0.60	61.2	33.29	10.592
29.75	3810.0	6.52	3.32	12.89	8.92	10.06	440.8	6.970	0.81	40.2	33.39	10.807
30 09	7371.9	6.69	3.54	14.04	8.96	10.11	545.7	6.970	3.03	26.6	33.49	10.871
16.87	3838.2	6.95	3 27	11.63	7.73	8.93	494.0	7.220	1.08	36.1	28.92	9.626
23.13	4112.5	6.45	2.67	11.92	8.56	9.79	477.7	8.930	1.24	57.2	33.53	10.764
12.34	2471.0	6.92	2.63	12.89	8.43	9.46	459.6	12.240	4.40	18.0	32.60	10.788
—	1897.3	4.63	5.08	9.42	7.86	9.08	500.0	8.100	1.40	107.1	—	9.881
6.27	4209.0	8.15	1.74	12.56	7.47	8.47	395.3	18.460	5.31	60.9	32.49	10.389
—	1037.0	9.64	2.00	16.50	7.40	8.63	282.6	16.540	10.51	53.2	—	10.343
—	994.2	8.43	1.17	14.91	7.85	9.00	284.0	13.340	3.55	43.7	—	10.381
—	2050.0	5.83	3.21	10.06	7.69	8.86	481.1	8.880	4.91	9.5	—	9.725
—	2074.0	7.97	2.25	12.81	7.97	9.18	498.5	8.180	3.09	16.0	—	9.997
5.97	2127.7	6.28	1.33	12.79	8.65	9.78	524.8	12.710	5.43	10.1	30.33	11.208
5.88	4318.4	7.86	1.68	14.80	8.19	9.44	512.7	10.960	4.53	6.1	30.72	10.604
5.09	1158.0	6.04	1.75	12.73	8.88	10.02	535.6	8.380	1.33	18.2	32.69	10.935
4.94	2318.2	7.33	0.99	15.70	9.47	10.70	566.2	7.960	2.12	5.1	30.06	11.624
4.79	4474 5	8.02	1.52	14.97	8.69	9.96	511.1	9.690	3.04	5.3	33 01	11.034
5.00	—	—	—	—	—	—	—	14.530	2.29	13.5	27.98	
5.37	2557.0	6 86	0.83	13.35	8.31	9.34	472.8	16.360	3.50	23.7	31.18	11.171
4.95	4295.0	7.77	0.84	15.67	8.64	9.72	515.9	11.200	3.40	13.7	32.54	10.956
5.18	3073.2	6.33	1.72	12.13	7.92	8.91	493.3	16.920	3.26	46.2	32.89	10.724
4.05	1883.2	7.29	0.75	13.90	9.08	10.27	517.0	8.940	1.31	14.7	30.90	11.275
4.11	3643.8	6.66	1.87	12.48	7.92	9.09	477.4	7.890	3.66	52.5	33.31	9.887
3.66	3488.5	6.68	2.00	12.47	8.04	9.24	486.9	9.750	3.48	14.8	31.46	10.239
3.43	5072.7	7.60	1.52	13.42	7.84	9.02	478.7	11.070	4.78	6.4	28.01	10.142
2.50	3834.7	7.13	1.16	11.65	7.30	8.34	445.0	14.340	5.37	6.0	25.77	9.740
2.24	3417.5	8.68	1.38	14.51	7.50	8.58	403.7	10.700	6.47	5.9	26.99	9.611
2.03	3769.6	8.59	1.17	14.88	7.44	8.42	391.8	8.640	4.41	10.5	30.52	9.211
1.79	3775.1	5.84	1.93	8.35	6.71	7.67	347.4	10.600	3.86	11.5	28.53	8.588
1.92	3876.0	8.46	1.17	14.47	7.95	9.00	410.9	9.070	4.19	10.5	27.38	9.896
1.78	4506.4	6.68	1 52	10.08	7.30	8.29	448.5	14.830	8.82	6.4	29.03	9.741
1.60	4904.7	7.37	1.33	10.62	6.74	7.75	350 2	9.720	4.03	11.2	29.17	8.583
1.68	2918.5	7.60	0.91	13.46	7.66	8.76	418.6	10.260	4.21	17.1	26.80	9.751
1.57	4132.0	6.24	1.29	10.11	7.84	8.94	408.7	10.270	3.33	14.8	29.74	9.970
1.95	1463.5	—	—	—	—	—	—	—	4.42	43.2	28.23	
2.11	4153.9	7.84	0.94	12.79	7.48	8.41	450.6	13 370	6.13	5.7	28.18	9.710
2.84	1601.1	8.31	1.18	13.85	7.01	7.99	378.9	6.010	2.24	5.9	29.15	8.497
2.59	1962.5	9.84	0.85	16.47	7.45	8.48	417.9	12.060	6.19	3.7	26.69	9.648
1.51	3786.0	8.59	0.86	13.43	6.95	7.48	375.4	5.040	1.86	11.1	27.88	8.255
1.60	4023.0	8.03	0.84	13.75	7.68	8.66	439.6	5.680	3 14	10.7	27.55	9.178
1.26	3860.0	10.74	0.96	14.32	6.14	6.95	353.8	10.100	5.63	5.7	27.00	7.719
2.01	208.4	—	—	10.56	7.03	8.20	384.1	8.250	0.94	9.9	28.89	8.942
1.72	2465.5	11.09	0.50	15.05	6.31	7.34	348.8	5.120	1.64	6.4	26.53	7.734
—	2360.5	15.87	—	13.86	4.06	4.69	98.6	0.307	—	—	—	4.707

ADMIRALTY INVESTIGATION.

ECONOMIC VALUES OF THE WELSH COALS.

Names of Coals employed in the Experiments.	Economic Evaporating Power, or Number of lbs. of Water evaporated from 212° by 1 lb. of Coal.	Weight of 1 Cubic Foot of the Coal as used for Fuel.	Weight of 1 Cubic Foot as calculated from the Density.	Ratio of B. to C., or of the Economical to the Theoretical Weight.	Difference per Cent. between Theoretical and Economical Weights.	Space occupied by 1 Ton in Cubic Feet (Economic Weight).	Results of Experiments on Cohesive Power of Coal (Percentage of Large Coal).	Evaporating Power of the Coal after deducting for Combustible Matter in Residue.	Weight of Water evaporated from 212° by 1 Cubic Foot of Coal.	Rate of Evaporation, or Number of lbs. of Water evaporated per Hour.
	A.	B. lbs.	C. lbs.	D.	E.	F.	G.	H.	I. lbs.	K. Mean.
Aberaman Merthyr.	10.75	48.900	81.910	.597	67.500	45.800	—	—	525.67	
Ebbw Vale . .	10.21	53.300	78.810	.676	45 980	42.260	45.0	10.64	544.19	460.22
Thomas's Merthyr .	10.16	53.000	82.290	.644	55.260	42.260	57.5	10.72	538.48	520.80
Duffryn . . .	10.14	53.220	82.720	643	55.430	42.050	56.2	11.80	540.12	409.32
Nixon's Merthyr .	9.96	51.700	82.290	.628	59.160	43.320	64.5	10.70	614.93	511.40
Bines . . .	9.94	57.080	81.357	.702	42.530	39.240	51.2	10.30	587.92	486.95
Bedwas . . .	9.79	50.500	82.600	.611	63.565	44.320	54.0	9.99	494.39	476.96
Hill's Plymouth Work	9.75	51.200	84.780	.603	65.680	43.740	64.0	10.18	499.20	531.60
Aberdare Company's Merthyr . .	9.73	49.300	81.730	.603	65.780	45.430	74.5	10.27	479.68	489.50
Gadly's 9-feet Seam	9.56	54.800	83.160	.658	51.750	40.870	76.0	10.46	523.88	517.30
Resolven . .	9.53	58.660	82.354	.712	40.390	38.190	35.0	10.44	559.02	390.25
Mynydd Newydd .	9.52	56.330	81.730	.689	45.090	39.760	53.7	10.59	536.26	470.69
Abercarn . .	9.47	50.300	83.220	.604	65.440	44.530	54.5	9.63	443.96	480.00
Anthracite, Jones & Co. . . .	9.46	58.250	85.786	.679	47.260	38.450	68.5	9.70	565.02	409.37
Ward's Fiery Vein .	9.40	57.433	83.850	.685	46 000	39.000	46.5	10.60	608.78	529.90
Neath Abbey . .	9.38	59.300	83.570	.709	49.920	37.770	50.0	9.65	556.23	546.10
Graigola . . .	9.35	60.166	81.107	.742	34.800	37.230	49.3	9.66	581.20	441.48
Gadly's 4-feet Seam	9.29	51.600	82.790	.623	60.440	43.410	68.5	10.73	479.36	400.00
Machen Rock Vein .	9.23	48.100	80.910	.594	68.210	46.560	52.5	9.43	443.96	488.75
Birch Grove, Graigola	9.22	51.000	84.850	.601	66.370	43.920	59.0	9.64	470.22	507.50
Llynvi . . .	9.19	53.300	80.350	.663	50.560	42.020	—	9.58	429.82	399.50
Cadoxton . .	8.97	58.100	85 970	.675	47.960	38.550	—	9.07	521.15	344.16
Oldcastle Fiery Vein	8.94	50.916	80.420	.633	57.946	43.990	57.7	—	455.18	464.30
Vivian and Sons' .	8.92	47.900	81.040	.591	69.180	46.760	54.0	9.11	427.26	421.25
Llangennech . .	8.86	56.930	81.850	.695	43.760	39.340	53.5	9.20	523.75	373.22
Three-quarter Rock Vein . . .	8.84	56.388	83.600	.674	48.260	39.720	52.7	—	498.46	486.86
Pentrepoth . .	8.72	57.720	81.730	.705	40.170	38.800	46.5	8.98	518.32	381.50
Cwm Frood Rock Vein	8.70	55.277	78.299	.706	41.648	40.520	72.5	9.38	480.90	379.80
Cwm Nant-y-Gros .	8 42	56.000	79.859	.701	42.600	40.000	55.7	8.82	471.52	404.16
Brymbo Main . .	8.36	47.000	81.100	.579	72.550	47.650	—	8.56	392.92	435.83
Vivian and Sons' Rock Vawr . .	8.08	48.900	81.160	.602	65.970	45.800	70.5	8.19	395.11	452.50
Coleshill . . .	8.00	53.000	80.483	.658	51.850	42.260	62.0	8.34	424.00	406.41
Brymbo Two-yard .	7.85	47.900	80.040	.598	67.110	46.760	79.5	7.91	376.00	441.66
Rock Vawr . .	7.68	55.000	80 210	.685	45.830	40.720	65.5	7.88	422.40	397.50
Porth-mawr . .	7.53	53.300	86.722	.614	62.700	42.020	62.0	7.75	401.34	347.44
Pontypool . .	7.47	55.700	83.350	.676	47.845	40.216	57.5	8.04	416.07	250.40
Pentrefelin . .	6.36	66.166	84.726	.781	28.051	33.850	52.7	7.40	489.62	247.24

ECONOMIC VALUES OF THE NEWCASTLE COALS.

Names of Coals employed in the Experiments.	Economic Evaporating Power, or Number of lbs. of Water evaporated from 212° by 1 lb. of Coal.	Weight of 1 Cubic Foot of the Coal as used for Fuel.	Weight of 1 Cubic Foot as calculated from the Density.	Ratio of B. to C., or of the Economical to the Theoretical Weight.	Difference per Cent. between Theoretical and Economical Weights.	Space occupied by 1 Ton in Cubic Feet (Economic Weight).	Results of Experiments on Cohesive Power of Coal (Percentage of Large Coal).	Evaporating Power of the Coal after deducting for Combustible Matter in Residue.	Weight of Water evaporated from 212° by 1 Cubic Foot of Coal.	Rate of Evaporation, or Number of lbs. of Water evaporated per Hour.
	A.	B. lbs.	C. lbs.	D.	E.	F.	G.	H.	I. lbs.	K. Mean.
Willington	9.95	53.2	79.870	.666	50.13	42.10	43.0	10.16	529.34	
Andrews House Tanfield	9.39	52.1	78.860	.660	51.36	42.99	—	9.80	489.21	351,20
Bowden Close	9.38	50.6	79.870	.633	57.84	44.26	38.5	9.67	474.62	—
Haswell Wallsend	8.87	47.4	80.230	.590	69.26	47.25	73.0	9.07	420.43	411.66
Newcastle Hartley	8.23	50.5	80.270	.629	58.95	44.35	78.5	8.65	415.61	308.00
Hedley's Hartley	8.16	52 0	81.790	.635	57.28	43.07	85.5	8.71	424.32	300.80
Bates' West Hartley	8.04	50.8	78.170	.649	53.89	44.13	69 5	8.26	408.43	406.80
West Hartley Main	7.87	48.9	78.860	.620	61.26	45.80	79.0	8.05	384.84	457.50
Buddle's West Hartley	7.82	50.6	77.110	.656	52.39	44.09	80.0	8.01	395.69	413.30
Hastings' Hartley	7.77	48.5	78.040	.621	60.90	46.18	75.5	7 96	376.84	404.50
Carr's Hartley	7.71	47.8	78.230	.611	63.66	46.86	77.5	8.13	368.53	344.30
Davison's West Hartley	7.61	47.7	78.360	.608	64.27	46.96	76.5	7.83	362.99	402.90
North Percy Hartley	7.57	49.1	78.290	.627	59.45	45.62	60.0	7.72	371.68	423.50
Haswell Coal Co.'s Steamboat Wallsend	7.48	49.5	79.360	.623	60.32	45.25	79.5	7.85	370.66	291.80
Derwentwater Hartley	7.42	50.4	78.790	.639	56.32	44.44	63.5	7.66	373.96	451.10
Broomhill	7.30	52.5	77.988	.673	48 55	42.67	65.7	7.66	383.25	397.78
Original Hartley	6.82	49.1	77.980	.629	58.81	45.62	80.0	6.98	334.86	428.40
Cowpen and Sidney's Hartley	6.79	47.9	78.670	.608	64.23	46.76	74.0	7.02	325.24	350.40

ECONOMIC VALUES OF CERTAIN DERBYSHIRE COALS.

	A.	B. lbs.	C. lbs.	D.	E.	F.	G.	H.	I. lbs.	K. Mean.
Earl Fitzwilliam's Elsecar	8.52	47.2	80.85	.583	70.29	47.45	77.0	8.78	402.14	412.70
Hoyland & Co.'s Elsecar	8.07	48.2	82.16	.586	70.45	46.47	82.5	8.43	388.97	372.91
Earl Fitzwilliam's Park Gate	7.92	47.0	81.79	.574	74.02	47.65	78.0	8.24	372.24	393.75
Butterly Co.'s Portland	7.92	47.1	81.16	.580	72.31	47.55	89.0	8.04	373.03	487.08
Butterly Co.'s Langley	7.80	47.8	78.86	.606	64.97	46.86	84.5	7.98	372.84	398.69
Stavely	7.26	49.9	79.79	.625	59.90	44.88	88.5	7.40	362.27	466.20
Loscoe Soft	6.88	44.8	80.17	.558	78.95	50.00	62.0	6.99	308 22	499.06
Loscoe Hard	6.32	45.9	79.60	.576	73.42	48.80	86.0	—	290.08	431.42

ECONOMIC VALUES OF THE LANCASHIRE COALS.

Names of Coals employed in the Experiments.	Economic Evaporating Power, or Number of lbs. of Water evaporated from 212° by 1 lb. of Coal.	Weight of 1 Cubic Foot of the Coal as used for Fuel.	Weight of 1 Cubic Foot as calculated from the Density.	Ratio of B. to C., or of the Economical to the Theoretical Weight.	Difference per Cent. between Theoretical and Economical Weights.	Space occupied by 1 Ton in Cubic Feet (Economic Weight).	Results of Experiments on Coheaive Power of Coal (Percentage of Large Coal).	Evaporating Power of the Coal after deducting for Combustible Matter in Residue.	Weight of Water evaporated from 212° by 1 Cubic Foot of Coal.	Rate of Evaporation, or Number of lbs. of Water evaporated per Hour.
	A.	B. lbs.	C. lbs.	D.	E.	F.	G.	H.	I. lbs.	K. Mean.
Ince Hall Co.'s Arley	9.47	47.6	79.36	.599	66.72	47.05	73.5	9.35	435.06	487.29
Haydock Little Delf	9.13	44.9	78.42	.572	74.65	49.88	66.5	9.26	409.93	532.91
Balcarres Arley .	8.83	50.5	78.17	.646	54.79	44.35	76.0	9.09	445.91	454.10
Blackley Hurst .	8.81	48.0	78.90	.608	64.37	46.66	65.0	9.00	422.88	500.80
Ince Hall Pemberton Yard . . .	8.78	48.0	84.10	.570	75.20	46.66	75.5	—	421.44	461.25
Haydock Rushy Park	8.74	49.3	82.54	.597	67.42	45.43	77.0	8.91	430.88	461.66
Moss Hall Pemberton Four-feet .	8.52	47.3	78.48	.602	65.91	47.35	71.5	8.65	402.99	480.00
Haydock Higher Florida . . .	8.39	49.5	75.99	.651	53.51	45.25	74.0	8.49	415.30	467.50
Ince Hall Pemberton Four-feet . .	8.34	51.8	79.60	.650	53.66	43.24	74.5	8.45	432.01	497.39
Blackbrook Little Delf . . .	8.29	51.0	78.16	.652	53.25	43.92	61.5	8.55	422.79	440.40
King . . .	8.17	50.8	81.10	.626	59.64	44.09	78.5	8.35	415.03	395.41
Rushy Park Mine .	8.08	47.0	80.04	.587	70.31	47.65	67.0	8.35	379.76	419.10
Blackbrook Rushy Park . . .	8.02	55.3	80.15	.689	44.93	40.50	80.5	8.26	443.50	481.20
Johnson and Wirthington's Rushy Park . . .	8.01	50.0	80.10	.624	60.20	44.80	69.0	8.16	400.50	454.50
Laffak Rushy Park .	7.98	52.6	84.07	.625	59.82	42.58	75.5	8.16	419.74	435.00
Balcarres Haigh Yard	7.90	50.8	80.10	.634	57.67	44.13	80.0	8.23	401.32	398.30
Haydock Florida Main . . .	7.83	48.0	79.04	.507	64.66	46.66	81.5	7.97	375.84	422.50
Wigan Four-feet .	7.77	53.4	75.49	.707	41.36	41.94	75.0	8.05	414.91	414.79
Ince Hall Pemberton Five-feet . .	7.72	51.8	79.17	.654	52.83	43.24	71.5	7.95	399.89	495.20
Cannel (Wigan) .	7.70	48.3	76.80	.628	59.00	46.37	95.0	8.06	371.91	381.10
Ince Hall Co.'s Furnace Vein . .	7.47	49.3	81.98	.601	66.28	45.43	71.5	7.84	368.27	435.21
Balcarres Lindsay .	7.44	51.1	78.61	.650	53.83	43.83	70.0	7.58	380.18	431.50
Caldwell and Thompson's Rushy Park	7.34	47.5	79.29	.599	56.92	47.15	76.0	7.43	348.65	449.79
Balcarres Five-feet .	7.21	49.0	79.11	.619	61.44	45.71	44.5	7.35	353.29	489.50
Moss Hall Pemberton Five-feet .	7.13	48.3	80.04	.603	65.71	46.37	78.5	7.29	344.37	417.18
Moss Hall Co.'s New Mine . . .	7.04	48.4	79.73	.607	64.73	46.28	76.5	7.16	340.73	422.08
Caldwell and Thompson's Higher Delf	6.85	48.4	79.48	.608	64.21	46.28	77.0	6.94	331.54	484.28
Johnson and Wirthington's Sir John	6.32	51.6	81.73	.631	58.39	43.41	82.0	6.62	326.11	362.70

ECONOMIC VALUES OF VARIOUS COALS.

	Names of Coals employed in the Experiments.	Economic evaporating Power, or Number of lbs. of Water evaporated from 212° by 1 lb. of Coal.	Weight of 1 Cubic Foot of the Coal as used for Fuel.	Weight of 1 Cubic Foot as calculated from the Density.	Ratio of B. to C., or of the Economical to the Theoretical Weight.	Difference per Cent. between Theoretical and Economical Weights.	Space occupied by 1 Ton in Cubic Feet (Economic Weight).	Results of Experiments on Cohesive Power of Coal (Percentage of Large Coal).	Evaporating Power of the Coal after deducting for Combustible Matter in Residue.	Weight of Water evaporated from 212° by 1 Cubic Foot of Coal.	Rate of Evaporation, or Number of lbs. of Water evaporated per Hour.
		A.	B. lbs.	C. lbs.	D.	E.	F.	G.	H.	I.	K. Mean.
Scotch Coals	Wallsend Elgin	8.46	54.60	78.611	.694	43.780	41.02	64.0	8.67	460.82	435.77
	Wellwood	8.24	52.60	79.780	.659	53.570	42.58	80.0	8.39	433.42	438.50
	Dalkeith Coronation Seam	7.71	51.66	78.611	.657	52.170	43.36	88.2	7.86	398.29	370.08
	Kilmarnock Skerrington	7.66	44.70	77.420	.577	73.190	50.11	63.5	7.82	342.40	470.83
	Fordel Splint	7.56	55.00	78.611	.699	42.920	40.72	63.0	7.69	415.80	464.98
	Grangemouth	7.40	54.25	80.480	.674	48.350	40.13	69.7	7.91	401.45	380.40
	Eglinton	7.37	52.00	79.840	.651	51.480	43.07	79.5	7.48	383.24	406.20
	Dalkeith Jewel Seam	7.08	49.80	79.672	.625	59.984	44.98	85.7	7.10	352.58	355.18
	Slievardagh Irish Anthracite	9.85	62.80	99.570	.630	58.550	35.66	74.0	10.49	618.58	473.18
Various	Coleshill Co.'s Bagillt Main	8.33	49.60	79.170	.626	59.610	45.16	79.0	8 50	413.16	461.25
	Ewlowe	7.02	50.40	79.540	.633	57.810	44.44	84.0	7.16	353.80	363.95
	Ibstock	6.91	47.30	80.540	.587	70.270	47.35	62.0	7.02	326.84	454.16
	Lydney (Forest of Dean)	8.52	54.44	80.046	.680	47.020	41.14	55.0	8.98	463.86	487.19
	Conception Bay, Chili	5.72	—	80.540	—	—	—	—	5.96	—	425.00
Patent Coals	Warlich's Patent Fuel	10.36	69.05	72.248	.955	4.490	32.44	—	10.60	715.35	457.84
	Livingstone's Steam Fuel	10.03	65.60	73.860	.888	12.590	34.14	—	10.57	657.96	483.95
	Lyon's Patent Fuel	9.58	61.10	74.730	.817	22.300	36.66	—	9.77	585.33	409.10
	Wylam's	8.92	65.08	68.629	.948	5.450	34.41	—	9.74	580.51	418.89
	Bell's	8.53	65.30	71.124	.918	8.910	34.30	—	8.65	557.00	549.11
	Holland and Green's	7.59	64.80	81.230	.797	25.350	34.56	—	7.86	491.83	470.00

AVERAGE VALUE OF COALS FROM DIFFERENT LOCALITIES.

Locality.	Evaporating Power, or Number of lbs. of Water evaporated from 212° by 1 lb. of Coal.	Rate of Evaporation, or Number of lbs. evaporated per Hour.	Weight in lbs. of 1 Cubic Foot of Coal as used for Fuel.	Space occupied by 1 Ton in Cubic Feet.	Results obtained in Experiments on Cohesive Power of Coals (Percentage of Large Coals).	Percentage Amount of Sulphur contained in Coals.
	A.	B.	C.	D.	E.	F.
Average of 37 samples from Wales	9.05	448.2	53.1	42.71	60.9	1.42
" 17 " Newcastle	8.37	411.1	49.8	45.30	67.5	0.94
" 28 " Lancashire	7.94	447.6	49.7	45.15	73.5	1.42
" 8 " Scotland	7.70	431.4	50.0	49.99	73.4	1.45
" 8 " Derbyshire	7.58	432.7	47.2	47.45	80.9	1.01

bottom, very nearly in geometrical progression, although the quotient is not the same under all circumstances. In one case it was found to be = 1.0727, when the temperature increased as follows:—floor, 18.36; at 2 feet, 18.36×1.072; 4 feet, 18.36×1.072^2; 6 feet, 18.36×1.072^3, &c.

The action of coal under steam boilers has been examined by Fyfe, who believed that the heat actually made available from coal in *practice*, is nearly the same as ought to be produced, according to theory, by the quantity of coke which it yields. If coal produces 50 per cent. of coke, for example. then 100 lbs. of the coal would boil 50×78.4 lbs. (Despretz) of water. According to Fyfe, 1 lb. of Scotch coal from Tranent will convert 5.61 lbs. of water into vapour from 0° C.; 1 lb. of the coke from this coal will boil 7.4 lbs. of water; 1 lb. of coal from Tranent yields 0.525 lb. of coke, which will consequently produce 3.9 lbs. of vapour, so that by carbonization there is a loss of heating power equivalent to $5.61 - 3.9 = 1.71$ lb. of vapour. In other experiments, the results with coal were 5.8 and 6.6, and with coke between 7.8 and 8.7. The greatest effect observed by Parkes was 8.68 lbs., and by Henwood, 9.96, with 1 part of the best Newcastle coal.

The difference in the amount of steam capable of being raised by coal from different localities, together with many other important physical properties upon which the economic value of this fuel depends, induced the Government of the United States to institute a series of practical experiments on the coal of different districts, with a view to ascertain the relative values of the different varieties, more particularly for generating steam and forging iron.

The entire investigation was entrusted to Professor W. R. Johnson, and the results were published in a Report to Congress in the year 1844 (pp. 696, 697). The importance of such an investigation in connection with the wants of the steam navy and various branches of national industry, led to a similar undertaking by the Government of Great Britain, which was superintended generally by Sir Henry de la Beche and Dr. Lyon Playfair, whose several Reports to Government were concluded in 1851.

The principal points to be looked for in steam fuel are thus stated by the British Commissioners:—

1. The fuel should burn so that steam may be raised in a short period, if this be desired; in other words, it should be able to produce a quick action.

2. It should possess high evaporative power, that is, be capable of converting much water into steam, with a small consumption of coal.

3. It should not be bituminous, lest so much smoke be generated as to betray the position of ships of war when it is desirable that this should be concealed.

4. It should possess considerable cohesion of its particles, so that it may not be broken into too small fragments by the constant attrition which it may experience in the vessel.

5. It should combine a considerable density with such mechanical structure that it may be easily stowed away in small space; a condition which, in coals of equal evaporative values, often involves a difference of more than 20 per cent.

6. It should be free from any considerable quantity of sulphur, and should not progressively decay, both of which circumstances render it liable to spontaneous combustion.

The results of these very extensive series of experiments are contained in the Tables given at pp. 696–701.

The following analyses and table of tests carried out at Portsmouth Dockyard give a comparative view of the quality and evaporative power of

Scotch steam coal from the Slamannan district, as against those of specimens of the best Welsh steam coals :—

Chemical analysis by Dr. Wallace, of Glasgow, of a sample of steam coal, No. 1, from Longrigg Colliery, of Messrs. James Nimmo & Co.

Volatile matters	Gas, tar, &c.	17.21	19.92
	Sulphur	0.33	
	Water, at 212° F.	2.38	
Coke	Fixed carbon	76.82	80.08
	Sulphur	0.41	
	Ash	2.85	
			100.00

	cwts. qr. lbs.
Coke, per ton of coal, 1,794 lbs., or	16 0 2
Specific gravity	1.304
Weight of a cubic foot in pounds	0.81
Space required for storage, cubic feet per ton	41½
Heating or evaporating power, *practical*, in pounds of water at 212° F., evaporated by the combustion of 1 lb. of coal	10.52 lbs.

This is a steam coal of remarkably fine quality. It gives a very high heating or evaporating power, and contains a very moderate proportion of ash and sulphur. It gives comparatively little flame and practically no smoke. This coal compares very favourably for navigation steam purposes with the best description of Welsh coal.

Comparative analysis of eight of the most renowned of the Merthyr and other steam coals from South Wales, and four of the best Scotch steam coals from the Slamannan district.

The Welsh coals mentioned are those which stand highest in order of merit in a report of trials made at the Portsmouth Dockyard.

The results from the Scotch coals are those obtained either by Government Dockyard trials or special analysis by renowned chemists.

WELSH STEAM COALS.

	Lbs. of Water evaporated by 1 lb. of Coal.	Percentage of Clinker & Ash.
Nixon's Navigation	10.05	5.37
Waynes Merthyr	10.05	5.37
Thomas ,,	9.79	5.47
Nauhudyn ,,	9.62	5.48
Ynsfaio ,,	9.52	6.76
Merthyr Dare	9.45	5.48
Resolven Merthyr	9.41	6.04
Insoles ,,	9.37	6.52
Average evaporating power	9.65	
Average percentage of clinker and ash		5 81

SCOTCH STEAM COALS.

	Lbs. of Water evaporated by 1 lb. of Coal.	Percentage of Clinker & Ash.
Broadrigg	10.21	2.52
West Longrigg	10.03	4.00
Roughrigg	10.00	2 99
Longrigg	9.56	3.77
Average evaporating power	9.94	
Average percentage of clinker and ash		3.32

TABLE SHOWING THE RESULTS OF TESTS OF LONGRIGG NAVIGATION AND WELSH STEAM COAL.

Date of Trial.	Coal used in Trial.	Name of Coal, and from what Contractor received.	Water evaporated by 1 lb. of Coal, calculated from the Temperature of 100°.	Water evaporated per Sq. Ft. of Fire-grate per Hour, calculated from the Temperature of 100°.	Percentage of Clinker and Ash.			Smoke.			Coal burnt per Sq. Ft. of Fire-grate per Hour.	Deposit of Soot.	Cinders re-burnt.	Temperature in Funnel.	Draught in Funnel.
					Clinker.	Ash.	Total.	Maximum Number.	Average Number.	Percentage of Time of no Smoke.					
1876.	cwts.		lbs.	lbs.							lbs.	lbs.	lbs.	deg.	in.
Aug. 30	10½	Longrigg Navigation Steam Coal, James Nimmo & Co. . .	9.26	227.80	3.06	2.38	5.44	2	0.85	28.30	24.89	8	36	710	[illegible]
Aug. 31	10½	Do. do. . .	9.23	223.63	3.32	2.38	5.70	2	1.34	6 40	24.17	9	38	707	[illegible]
Sept. 1	20	Do. do. . .	9.25	219.12	3.48	1.92	5.40	1	0.61	38.50	23.63	15	66	703	[illegible]
Sept. 2	10½	½ Hood's Merthyr, ½ Longrigg Navigation	9.47	223.82	2.98	2.55	5.53	1	0.34	65.70	24.00	9	37	69[illegible]	[illegible]
Sept. 4	10½	⅝ Hood's Merthyr, ⅜ Longrigg Navigation	9.47	226.08	3.32	2.30	5.62	2	0.38	62.70	24.00	9	33	681	[illegible]
July 29	10½	Hood's Merthyr (as used in preceding trials)	9.79	230.32	2.64	2.04	4 68	2	0.57	54.60	24.17	9	36	681	[illegible]
Oct. 1*	10½	Cowpen Cambois Hartley . .	8.23	239.40	2.38	1.36	3 74	4	1.93	5.42	27.77	7	31	793	[illegible]

* Trial made Portsmouth Dockyard November 4, 1875. (Added to this return for purposes of comparison.)

The evaporating vessels employed in the American and British researches were of different construction. In the former, a cylindrical boiler, 30 feet in length by $3\frac{1}{2}$ in diameter, was set over a furnace, and the heated gases, after passing through two interior return flues, each 1 foot in diameter, escaped by side flues, exterior to the boiler, to the chimney, making the entire length of circuit for the products of combustion 121 feet. The grate surface was $16\frac{1}{4}$ square feet, and the area of heat-absorbing surface $377\frac{1}{2}$ square feet, so that the ratio of grate surface to absorbing surface was as 1 to $23\frac{1}{3}$. The chimney was 63 feet high, with a cross section of 324 square inches.

In the experiments of the British Commission, a Cornish boiler was used, 12 feet long and 4 feet external diameter, with an interior flue 2 feet in diameter, within which the furnace was built. The heated gases from the furnace, after traversing the central flue, returned to the front by two side flues external to the boiler, and escaped by a common flue passing under the bottom of the boiler to the chimney, making a circuit of altogether 36 feet in length. The surface of grate was 5 square feet, and the heat-absorbing surface was 197.6 square feet, and the ratio of grate surface to absorbing surface consequently as 1 to $39\frac{1}{2}$; the chimney was $35\frac{1}{2}$ feet high, and had a cross section of $182\frac{1}{4}$ square inches. The amount of coal burned during the whole series of 144 trials at Washington was $62\frac{1}{2}$ tons; that consumed in the 82 trials at London was $14\frac{1}{8}$ tons; the average weight of coal burnt at one trial in the former case being 978 lbs., and in the latter $391\frac{1}{2}$ lbs.

In the Table of American results, the bulk occupied by a cubic foot of coal is estimated on the coal in the condition in which it is sent into the market, large and small together. The corresponding column in the series of British experiments has reference to the coal broken into pieces, none of which exceeded a pound in weight. A greater uniformity of result is certainly to be expected from the latter mode of proceeding, and the amount of steam raised by equal bulks of coal measured in these two methods will be in favour of the latter.

In comparing, therefore, the relative values of the coal by measure, which is of importance for ships' use, the mode of measurement or the size of the pieces must be taken into account, and if those coals in the two series of experiments be compared whose specific gravities are identical, it will be found that on an average a cubic foot in the marketable state will weigh 10 per cent. less than a cubic foot broken into pieces, none of which exceed 1 lb. in weight. The amount of steam raised per cubic foot of coal will therefore require to be increased 10 per cent. in the American experiments to make the results strictly comparable with those of the British researches.

In the British experiments, the amount of moisture contained in the coal was not deducted in calculating the evaporative value, as it was considered more practical to test their values in the condition in which they were sent to market. The boiler employed by the British Commissioners was, from its small size, not calculated to exhibit the maximum effect obtainable from the fuel, being 20 per cent. less efficient than the boilers employed at the Cornish mines; but as all the varieties of coal were submitted to the same treatment, it was presumed that their relative values would be elicited from a comparison of the results obtained.* Three experiments were made with each fuel. A different amount of air was admitted to the grate in many of the trials, by means of a damper in the chimney, and a mean was taken of the quantity of steam raised in each case, which was supposed to indicate the practical value of the coal; in others the same amount of air was admitted, or the area of the chimney was kept constant

* This is a serious objection to these researches, as different descriptions of coal require very different treatment, and Cornish boilers different management from marine boilers.

in all three trials. It would have been very desirable if the amount of air admitted to the fuel, as well as the mode of its admission, had been varied, to a greater extent than was done in these experiments, so as to have ascertained the greatest possible practical efficiency of each variety of coal, and, if possible, to have ascertained the conditions required by specimens of different physical and chemical constitution, in order that their full calorific value might be developed. In many instances too much, in others too little, air appears to have been admitted, although the fact of no combustible ingredients being found amongst the gases which escaped from the chimney implies that the carbon had been completely converted into carbonic acid.

The relation between the composition of the coal, as ascertained by analysis, and its value for producing steam, is not by any means very clearly brought out by the experiments, which indeed prove that the only trustworthy method of determining the value of a fuel, especially for steam purposes, is that of practical use under the boiler, where several tons and not lbs. are consumed.

Recent results observed in engineering practice with coal used in steam-boiler furnaces have led to the conclusion that coal has a greater evaporating power as so used than its thermal equivalent as usually ascertained shows to be possible. In addition to this, results repeatedly obtained of late years with liquid fuels have completely upset all thermal calculations founded upon their ultimate chemical composition. It is of course easy to dismiss such results as mythical, or to endeavour to explain them away by suggesting priming of steam boilers or some other abnormal action which would vitiate the result, but it is surely much wiser to accept them as an incentive to fresh inquiry as to the direction in which it may be possible to improve our methods of estimation.

One writer* some time ago suggested that the temperature of ignition must be added in estimating the heating value of fuels, but it is impossible that this element can enter into estimates of the *quantity* of heat available from the combustion of fuel. Combustion is chemical combination which is possible only under certain conditions, and these include the physical state of the substances and a given minimum temperature which is a *static* condition essential to the production of the phenomena.

Another writer† endeavours to find in the degree in which the effect of *radiant* heat is utilized the solution of all questions as to difference in heating effects. This, however, although it may influence the methods of applying fuel, cannot help us in estimating the quantity of heat which may be obtained from its combustion. The amount of radiant heat produced varies with the calorific intensity or temperature of combustion, and not with the calorific value of the fuel.

A glance at the defects of existing methods of estimation may enable us to see more clearly what is required in the way of improvement.

1. The calorimetric method is objectionable because it operates upon very minute quantities of the substance which is being tested;‡ the gaseous products of combustion, when allowed to rise in bubbles through the water in the calorimeter, have been found to be not completely cooled, thus causing a "not unimportant" loss of heat;§ and the dense fumes generally given off "indicate that the combustion itself is incomplete."‖ The combustion is usually conducted rapidly in a confined space, in presence of the resulting products, so that it might well be incomplete, besides being thus conducted

* "Engineering," July 28, 1882.
† The "Engineer," October 21 and November 11, 1887.
‡ See W. Anderson in Inst. C.E. lectures on "Heat in its Mechanical Applications," 1883.
§ Percy, "Metallurgy," vol. Fuel, p. 541.
‖ J. Goodman in the "Engineer," November 4, 1887.

at a low temperature. The oxygen is frequently derived from the decomposition of some solid substance, and the carbonic oxide which passes off is necessarily formed by decomposition of the carbonic acid in presence of the glowing carbon, both of these actions absorbing heat. Even in the results obtained with Favre and Silbermann's calorimeter, carbonic oxide was found, and it is well known that this gas is not formed as the result of a primary combustion, although the amount of heat absorbed in producing it from carbonic acid is not fully known. For in addition to the absorption of heat due to change of volume, it is to be observed that as oxygen combines as O_2, work must be expended in separating that duplex molecule when CO results from the action

$$CO_2 + C = 2CO.$$

2. The untrustworthiness of the method of calculating theoretical calorific power is due to a variety of causes. First of all, there is the uncertainty as to the value to be ascribed to the elements themselves.

Favre and Silbermann found considerable difference between the calorific powers of five varieties of pure carbon, as follows:*—

	Calorific Power.		Specific Heat (Regnault).
Wood charcoal	8080.0	...	0.24150
Gas retort carbon . . .	8047.3	...	0.20360
Artificial graphite . . .	7762.3	..	0.19702
Native graphite . . .	7796.6	...	0.20187
Diamond	7770.1	...	0.14687

so that they concluded that "there is no exact relation between the calorific power and the specific heat of carbon in the different allotropic states." It appears also from these results that "the heat of combustion of an elementary substance depends not only upon its chemical constitution, but also upon its physical state before combustion."†

Favre and Silbermann noticed that the density of both simple and compound bodies exerts an influence on their calorific value, and showed that "the fuel value of polymeric bodies varies with the state of condensation of their molecules, with which it is in inverse ratio." They applied the same observation to simple bodies in different allotropic conditions, for while carbon vapour is valued at 11,214 calories, natural graphite is only 7,796.6, and diamond 7,770.

All calculations of the calorific value of fuels proceed on the assumption that the carbon of the fuel exists in it as solid carbon, in which state it is to be taken as of the value of wood charcoal burning to carbonic acid, although it is certain that this is wide of the mark for both solid and liquid fuel—even apart from the fact that a large portion of the carbon must burn in the state of gas.

In addition to this uncertainty about carbon, there is the fact that all estimations of the calorific power of hydrogen have been made with that substance in the state of gas. Little is known about it in other states, but it is certain that neither in coal nor in liquid fuel does it exist as a gas, although it may be gasified before either fuel is ignited. In assuming, therefore, that the calorific power of solid or liquid hydrogen is the same as that of gaseous hydrogen "we commit an error," as Professor Rücker remarks,‡ "of the existence of which we are certain, while we are totally ignorant of its magnitude."

All ordinary analyses of fuels give simply their ultimate chemical composition or the proportions of the several elementary substances into which

* See Percy, "Fuel," p. 163.

† "Coal, its History and Uses," p. 243 (London: Macmillan, 1878).

‡ *Ibid.*, p. 246.

they are resolved. In analyses of coal, we have usually the percentage proportions of carbon and hydrogen into which the coal has been resolved by the action of heat.

Of the proximate composition of coal but little is known, but it is recognized that it consists for the most part of *solid hydrocarbons*, and is not a mere mixture of carbon and hydrogen. Extremely little progress has been made in isolating any of these hydrocarbons in their natural state by chemical methods, and it is very doubtful if they can be successfully separated from one another. When heat is applied to coal, it is well known that gaseous hydrocarbons, of different composition, are formed by reactions taking place within the substance of the coal, and finally a certain quantity of so-called "fixed carbon," or, more properly, deposited carbon, remains after all the gaseous hydrocarbons have been driven off.

The fact is often overlooked that the composition of the hydrocarbons formed by the action of heat on coal, as well as the physical state of the resultant carbon, depends on the temperature to which the coal has been exposed during distillation or decomposition, and since the calorific value of the different hydrocarbons varies with their constitution, and that of solid carbon with its physical state, it is evidently not easy at present to trace any exact relation between the results yielded by any given coal on analysis and those found in practical use.

We do not know, therefore, what coal is proximately composed of—in what way the elements are combined in its substance—or what is the calorific value of its various ingredients or of the compounds which may be produced by treating it at different temperatures.

In the face of such elements of uncertainty, it is not surprising that Messrs. Scheurer-Kestner * and Meunier-Dollfus found wide variations between the experimental and calculated calorific values of different varieties of coal, and also between those of different specimens of coal which yielded practically the same results on analysis.

Several of the most striking of their results were published by Dr. Percy † in the following table, which, however, contains only instances in which the experimental result exceeded considerably the theoretical or calculated calorific power :—

No	Locality.	Description of Coal.	Percentage Composition of the Coal, exclusive of Ash and Water.			Calorific Power calculated on the Dry Coal free from Ash.		Coke per Cent. calculated on the Dry Coal free from Ash.
			Carbon.	Hydrogen.	Oxygen and Nitrogen.	Experimental.	Theoretical.	
1	Manosque, Basses-Alpes	Lignite .	66.31	4.85	28.84	6,991	5,782	46.76
2	,, ,,	Lignite .	70.57	5.44	23.99	7,363	6,533	47.55
3	Louisenthal, Saarbrück	Not stated	76.87	4.68	18.45	8,215	7,056	59.49
4	Duttweiler, Saarbrück	Not stated	83.82	4.60	11.58	8,724	7,871	63.58
5	Ronchamp	. . . .	88.38	4.42	7.20	9,117	—	71.58
6	Creusot	Caking .	88.48	4.41	7.11	9,622	8,384	80.42
7		Non-caking	90.79	4.24	4.97	9,293	8,585	84.12
8		Anthracite	92.36	3.66	3.98	9,456	8,553	88.15

Nos. 5 and 6 illustrate the case of two specimens of coal which show practically the same percentage composition on analysis, but have more than 5 per cent. difference in calorific power; whilst 6 shows a smaller proportion of carbon combined with a greater calorific power than 7 exhibits, although the available hydrogen is practically the same in both. The

* *Ann. de Chim. et de Phys.*, ser. 4, 1870, xvi. p. 436; ser. 4, 1872, xxvi. p. 80.
† "Metallurgy," vol. Fuel, p. 539.

difference between experimental and calculated calorific powers amounted in some instances to 15 per cent.

In the case of two specimens of coal from England (not given in the table), the calculated heat was also too small; but in the case of some kinds of brown coal from France and Germany it was larger than the experimental result, while there was not much difference between the experimental and calculated results in the case of several kinds of coal from Russia.

The correctness of some of these results was assailed by Bunté, Stohmann, and Fischer, but Scheurer-Kestner * succeeded in maintaining their accuracy against the objections of his critics.

Dr. Percy remarks that Scheurer-Kestner endeavoured to explain the difference in calorific power between Nos. 5 and 6 "by attaching a higher calorific value to the carbon which remains in the coke formed than to that which is evolved during the process of coking;" but this hypothesis will not explain the discrepancy in the cases of 6 and 7.

Grüner † inclined, it is said, to Scheurer-Kestner's view, whilst Von Hauer ‡ ascribed an increase of calorific power to increased age of geological formation. The conclusion which is, however, expressed by Dr. Percy is undoubtedly the most weighty which has been announced. "It is the author's opinion," he said,§ "that a thorough investigation by competent analysts into the proximate chemical constitution of coal, which is at present wholly unknown, is a necessary prelude to any trustworthy explanation of the differences in question."

Until that most desirable goal is reached, it is worth consideration whether we cannot approximate our method of estimating calorific power more closely to the actual conditions under which fuel is used.

If specimens of coal, for instance, were resolved into gaseous hydrocarbons and fixed carbon at a series of ascending temperatures, or at a minimum and a maximum temperature, the volume and composition of the gases given off at each temperature respectively could be observed, as well as the quantity and physical state of the "fixed carbon" in each case. The quantity of sulphur, nitrogen, and ash contained in the coal would also be estimated, and the influence, if any, of the nitrogen on the combustion of the carbon might be investigated.

If now to the calorific value of the solid carbon thus obtained we were to add that of the hydrocarbon gases evolved, it is probable that we should have in result a tolerably close approximation to the quantity of heat which would be yielded by the coal on combustion at any temperature within the limits used in this process. Moreover, on knowing the temperature at which any sample of coal had been thus resolved or analysed (which temperature should always be stated in the report of analysis), and comparing its yield and quality of gas and carbon with standard observations on representative kinds of coal at different temperatures, it would probably be a simple matter to estimate the value of that particular coal for use at any given temperature.

This method would probably in some cases yield results similar to those obtained by the one proposed by M. Cornut, chief engineer to the Northern (of France) Steam Users' Association, which he expressed by the formula—

$$Q = 8{,}080C' + 11{,}214C'' + 34{,}462H,$$

where Q = the total quantity of heat,
C' = the fixed carbon, and
C'' = the volatile carbon, contained in the coal.

* See *Ann. de Chim.*, &c., vol. viii. pp. 267, 281; "Bull. Soc. Chem."
† *Jahresbericht Chem.*, p. 1187 (1874).
‡ *Jahrbuch für Min. Geol.*, p. 727 (1863).
§ "Fuel," p. 539.

This latter method, however, takes no account of the variation in thermic value arising from the temperature at which coal is decomposed, and consequently does not distinguish the calorific values of the hydrocarbons produced according to the temperature of their formation. It must thus fail under certain circumstances, although it is a decided improvement upon existing formulæ.

In dealing with liquid fuel, we are upon similar ground. The calorific value of this form of fuel has hitherto been calculated in the same way as that of coal, and hence it appears that too low an estimate has been formed of its value. The point aimed at, consequently, in most of the trials with this fuel, has been the realization merely of a close approximation to the calorific value of the carbon and hydrogen estimated by analysis *as if existing separately in the fuel.* Such estimates have rarely credited liquid fuels with double the calorific value of good coal, but evaporative results, which could not but be considered startling in that view of the value of the fuel, have been obtained by Admiral Selwyn and others (see "Liquid Fuel," pp. 316–330), and, although they have frequently been received with incredulity, there is no doubt that they go far towards showing that the method of estimation must be defective.

There has no doubt been a wide variety in the results obtained by different methods of using liquid fuel, and even with the same method under different circumstances, but this has been due to imperfections in the apparatus used and to want of experience in the best method of treating the fuel.

There has also been difficulty in understanding how such high results as four times the evaporative rate of coal could be legitimately obtained with a fuel which was stamped by recognized methods with a definite calorific value very far below this.

It is evident that it is on its ability to yield gas of high calorific power that the value of any fuel rests, and that in order to use fuel successfully efforts must be directed to the complete production and utilization of this gas.

These considerations show that what is required in estimating the calorific power of fuel is, to imitate as closely as possible the conditions of actual use; turning the fuel into gas—with or without steam—estimating the quantity and quality of the gas produced, and of course allowing for the steam where it is used; and determining the calorific value of the fuel from that of the gas which is invariably present and is the immediate cause of combustion when fuel is used.

Another important feature in steam-coal is the character of the ash, which ought to be infusible, so as to fall through the grates as soon as produced. An ash which melts, forming *clinkers* or *scars*, is very objectionable, from the obstruction they offer to the draught, the extra labour and wear and tear of stoking, and the cooling effects of the rush of cold air through the flues while the fireman is clearing his grates. This property is overlooked in these and similar researches, as the combustion is conducted too leisurely, and at a temperature inside the fire-place which does not test this character of the ash. The stoking on board a steamer in a gale of wind had no counterpart in these land experiments, and the highest evaporative power is comparatively worthless if associated with a fusible ash. All these difficulties could be met, however, by converting the coal into gas before burning it in the furnace.

Another feature of steam-coal, somewhat more difficult to describe, is the peculiar facility which some kinds of this coal possess of forming a long flame, which is of more value than mere high evaporative power tested under conditions rarely or never realized in actual practice.*

* See section 3, p. 323, of British Commissioners' requirements.

Very important comparative results with different kinds of boilers are to be found in the Minutes of Proceedings of the Institution of Civil Engineers, vols. xlvi. (D. K. Clark, On the Evaporative Performance of Steam Boilers), lii. (J. A. Longridge, On the Evaporative Power of Locomotive Boilers); in the Transactions of the Royal Agricultural Society of Great Britain for 1872 and subsequent years; in the Report of the Committee of the Smoke Abatement Exhibition, London; and in the Reports of Trials of Boilers at the Fair of the American Institute in 1871 and at the Philadelphia Exhibition in 1876.

Tests of gas-fired boilers have been referred to *ante*.

Some are inclined to consider the total amount of carbon as a measure of the practical evaporative power of coal, and amongst these Professor Johnson, who has adduced Table I., given at p. 712, in support of this test. The evaporative trials were performed by burning about 2 tons of each kind of coal under a boiler capable of evaporating 15 cubic feet of water per hour.

The correspondence between the 15th and 18th columns appears to demonstrate that the heating power of bituminous coals is practically proportionate to the carbon which they severally contain. On the average, 85.35 per cent. of the heating power of the coals was consumed in evaporating water from the boiler, and 14.65 per cent. was carried away by the products of their combustion.*

The average excess of hydrogen for the six varieties, as deduced from columns 13 and 14, is 4.636 per cent, which, calculated on the assumption that 1 part by weight of hydrogen is capable of raising 62.535 (Dulong) parts of water 1° F., ought to have an evaporative power of 2.814. This would raise the average in the 15th column from 10.7 to 13.514 as the calculated evaporative power of the unit of combustible matter, showing the calculated to be 26.3 per cent. higher than the experimental effect. With our existing arrangements for burning fuel, therefore, either time is not allowed for any of this heat to be made available, or the hydrogen, by passing from the solid state as it exists in the coal, to the gaseous condition as an ingredient of aqueous vapour, and by rendering a large portion of the carbon gaseous in the form of hydrocarbons, appears to be rendered valueless as a constituent of coal. Whether this apparent loss is necessarily the case, or whether by employing condensed air to feed the fire and replace the action of the chimney, as proposed by Mr. Prideaux, together with an improved regulation of the quantity of air and mode of admitting it, much of this heat might not be economized, remains still a problem for full solution.

The amount of oxygen consumed by fuel in burning, or the amount of oxide of lead reduced to the state of metal, has been also assumed to be a measure of its evaporative value. The extent to which this and the two preceding methods of computation are trustworthy, as elicited by the extensive series of experiments of the Admiralty investigation, will be seen by the following Table, in which the actual amounts of steam raised are placed in juxtaposition with the quantities of lead reduced, the total amounts of carbon, and the total quantities of coke left by the coal on charring. An additional column shows the amount of carbon contained in the volatile matters.

* This result is opposed to that found by Mr. L. Thompson, in experiments made on a considerable scale at the Western Gas Works, and for a general discussion of this point see Dr. Ure's "Dictionary of Manufactures, &c."

TABLE I.

Designation of the Coal.	Specific Gravity.	Proximate Analysis. Composition of Raw Coal in 100 Parts. Moisture expelled below 250° F.	Sulphur.	Volatile Combustible Matter.	Fixed Carbon.	Earthy Matter.	Ratio of Fixed to 1 of Volatile Combustible Matter.	Ultimate Analysis, calculated for 100 Parts of Combustible Matter. Carbon.	Hydrogen.	Oxygen and Nitrogen.	Calculated Evaporative Power of the Carbon alone in one of Combustible Matter, by Dulong's Co-efficient for Water at 212°.	Practical Evaporative Power. Pounds of Water from 212° to 1 of Combustible Matter. Evaporated from the Boiler.	Vaporizable by the Heat expended on the Gaseous Products of Combustion.	Total of Evaporative Efficiency of One Part of Combustible Matter by Experiment on a Practical Scale.	Difference between the Calculated and the Experimental Efficiency of the Combustible Matter.
Summit Postage Railroad, Cambria Co. Pa.	1.3617	0.700	1.500	18.197	64.245	15.360	3.535	91.955	5.876	2.178	11.522	10.238	1.3120	11.550	- .028
Midlothian "new shaft" . . . Vir.	1.3006	0.914	2.282	29.274	62.050	5.480	1.966	93.620	5.739	0.641	11.731	10.191	1.2690	11.460	+ .272
Newcastle . . . . . Eng.	1.2567	1.461	—	28.312	68.377	1.850	2.415	84.157	5.626	10.218	10.545	9.178	1.7200	10.898	- .353
Clover Hill . . . . . Vir.	1.2887	1.277	0.514	28.409	65.425	4.375	2.268	83.393	4.958	11.649	10.445	8.588	1.9490	10.537	- 082
Scotch	1.2759	1.365	—	35.586	60.342	2.707	1.696	82.952	5.607	11.441	10.393	8.868	1.3380	10.206	+ .187
Careyville, Kentucky, and Cannelton . Ind.	1.3920	1.150	—	30.669	44.493	23.687	1.450	76.335	6.663	17.002	9.565	7.734	1.8230	9.557	+ .008
Averages	—	—	—	—	—	—	—	—	—	—	10.700	9.133	1.6585	10.701	

In calculating the evaporative power the latent heat of steam is taken at 1030°. The waste or residue unburnt and the incombustible matters are deducted, and both the calculated evaporative power of the carbon constituent, and the total evaporation by experiment, are referred to and calculated for, 1 part by weight of combustible matter. 1 part of carbon is assumed with Dulong to be capable in burning of heating 7,170 parts of water 1° C., or 12,906 parts 1° F.

TABLE II.

	Names of Coals employed in the Experiments.	Lbs. of Water evaporated by 1 lb. of Coal.	Lbs. of Lead reduced from Litharge by 1 of Coal.	Total Amount of Carbon contained in 100 of Coal	Coke or Fixed Carbon left by 100 of Coal, Ash deducted.	Carbon contained in Volatile Matter of Coal.
Welsh Coals	Aberaman Merthyr	10.75	32 0	90.90	83.55	7.39
	Ebbw Vale	10.21	32.0	89.78	76.00	13.78
	Thomas's Merthyr	10.16	33.0	90.12	84.85	5.27
	Duffryn	10.14	30.0	88.26	81.04	7.22
	Nixon's Merthyr	9.96	33.2	90.27	77.86	12.41
	Binea	9.94	31.6	88.66	84.14	4.52
	Bedwas	9.79	28.2	80.61	64.76	15 85
	Hill's Plymouth Work	9.75	34.1	88.49	79.86	8.63
	Aberdare Company's Merthyr	9.73	34.1	88.28	82.57	5.71
	Gadly's Nine-feet Seam	9.56	34.2	86.18	81.20	4.98
	Resolven	9.53	32.2	79.33	74.49	4.84
	Mynydd Newydd	9.52	30.5	84.71	71.56	13.15
	Abercarn	9.47	31.8	81.26	66.36	14.90
	Anthracite, Jones and Co.	9.46	33.5	91.44	91.38	0.06
	Ward's Fiery Vein	9.40	31.5	87.87	—	—
	Neath Abbey	9.38	31.2	89.04	57.87	31.17
	Graigola	9.35	32.1	84.87	82.26	2.61
	Gadly's Four-feet Seam	9.29	34.2	88.56	83.35	5.21
	Machen Rock Vein	9.23	30.7	71.08	61.35	9.73
	Birch Grove, Graigola	9 22	33.3	84.25	80.67	3.58
	Llynvi	9.19	32.2	87.18	69.90	17.28
	Cadoxton	8.97	31.8	87.71	78.43	9.28
	Oldcastle Fiery Vein	8.94	31.4	87.68	77.16	10.52
	Vivian and Sons' Merthyr	8.82	31.0	82.75	61.79	20.96
	Llangennech	8.86	32.7	85.46	77.15	8.31
	Three-quarter Rock Vein	8.84	26.6	75.15	51.54	23.61
	Pentrepoth	8.72	31.2	88.72	79.14	9.58
	Cwm Frood Rock Vein	8.70	28.3	82.25	62.80	19.45
	Cwm Nant-y-Gros	8.42	29.7	78.36	60.00	18.36
	Brymbo Main	8.36	30.3	77.87	51.18	26.69
	Vivian and Sons' Rock Vawr	8.08	30.0	79 09	54.30	24.79
	Coleshill	8.00	26.1	73.84	47.08	26.76
	Brymbo Two-yard	7.85	29.5	78.13	50.30	27.93
	Rock Vawr	7.68	28.9	77.98	54.95	23.03
	Porth-mawr	7.53	24.8	74.70	48.38	26.32
	Pontypool	7.47	31.5	80.70	59.28	21.42
	Pentrefelin	6.36	30.5	85.52	78.91	6.61
Newcastle Coals	Willington	9.95	31.3	86.81	71.11	15.70
	Andrews House Tanfield	9.39	31.1	85.58	62.99	22.59
	Bowden Close	9.38	31.9	84.92	67.41	17.51
	Haswell Wallsend	8.87	31.5	83.47	62.50	20.97
	Newcastle Hartley	8.23	31.9	81.81	57.47	24.34
	Hadley's Hartley	8.16	30 4	80.26	63.19	17.07
	Bates' West Hartley	8.04	28.9	80.61	—	—
	West Hartley Main	7.87	30.3	81.85	56.59	25.26
	Buddle's West Hartley	7.82	29.5	80.75	—	—
	Hastings' Hartley	7.77	28.6	82.24	32.66	49.58
	Carr's Hartley	7.71	30.9	79.83	55.42	24.41
	Davison's West Hartley	7.61	30.1	82.26	53.65	28.61
	North Percy Hartley	7.57	29.1	80.03	53.96	26.07
	Haswell Coal Company Steam-boat Wallsend	7.48	31.5	83.71	55.45	26.26
	Derwentwater Hartley	7.42	29.1	87.01	51.10	35.91
	Broomhill	7.30	25.5	81.70	56.13	25.57
	Original Hartley	6.82	26.6	81.18	55.15	26.03
	Cowper and Sydney Hartley	6.79	28.7	82.20	56.23	25.97

TABLE II—(*continued*).

	Names of Coals employed in the Experiments.	Lbs. of Water evaporated by 1 lb. of Coal.	Lbs. of Lead reduced from Litharge by 1 of Coal.	Total Amount of Carbon contained in 100 of Coal.	Coke or Fixed Carbon left by 100 of Coal, Ash deducted.	Carbon contained in Volatile Matter of Coal.
Derbyshire Coals	Earl Fitzwilliam's Elsecar	8.52	30.1	81.93	59.14	22.77
	Hoyland and Co.'s Elsecar	8.07	29.7	80.05	58.77	21.28
	Earl Fitzwilliam's Park Gate	7.92	30.1	80.07	59.90	21.17
	Butterly Co.'s Portland	7.92	31.0	80.41	59.67	20.74
	Butterly Co.'s Langley	7.80	30.0	77.97	50.25	27.72
	Stavely	7.26	28.1	79.85	55.46	24.39
	Loscoe Soft	6.88	28.0	77.49	50.50	26.99
	Loscoe Hard	6.32	29.6			
Lancashire Coals	Ince Hall Co.'s Arley	9.47	32.5	82.61	62.47	20.14
	Haydock Little Delf	9.13	29.3	79.71	54 68	25.03
	Balcarres Arley	8.83	29.4	83.54	59.57	23.97
	Blackley Hurst	8.81	29.6	82.01	53.79	28.22
	Ince Hall Pemberton Yard	8.78	30.0	80.78	58.26	22.52
	Haydock Rushy Park	8.74	29.8	77.65	55.72	21.93
	Moss Hall Pemberton Four-feet	8.52	28.5	75.53	49.12	26.41
	Haydock Higher Florida	8.39	29.7	77.33	48.05	29 28
	Ince Hall Pemberton Four-feet	8.34	28.8	77.01	56.01	21.00
	Blackbrook Little Delf	8.29	28.7	82 70	54.17	28.53
	King	8.17	31.3	73.66	53.68	19.98
	Rushy Park Mine	8 08	29.0	77.76	50.97	26.79
	Blackbrook Rushy Park	8.02	30.4	81.16	55.42	25.74
	Johnson and Worthington's Rushy Park	8.01	28 9	79.50	55.33	24.17
	Laffak Rushy Park	7.98	26 9	80.47	53.44	27.03
	Balcarres Haigh Yard	7.90	28.2	82.26	62.19	20.07
	Haydock Florida Main	7.83	29.3	77.49	52.38	25.11
	Wigan Four-feet	7.77	30.0	78.86	55.77	23.09
	Ince Hall Pemberton Five-feet	7.72	28.7	68.72	42.16	26.56
	Cannel (Wigan)	7.70	29.9	79.23	55.49	23.74
	Ince Hall Co.'s Furnace Vein	7.47	28.6	74.74	54.36	20.38
	Balcarres Lindsay	7.44	26.2	83.90	55.85	28.05
	Caldwell and Thompson's Rushy Park	7.34	29.4	76.17	57.20	18 97
	Balcarres Five-feet	7.21	26 0	74.21	46.69	27.52
	Moss Hall Pemberton Five-feet	7 13	27.5	76.16	50.08	26.08
	Moss Hall Co.'s New Mine	7.04	27.0	77.50	54.54	22.96
	Caldwell and Thompson's Higher Delf	6.85	28.4	75.40	48.25	27.15
	Johnson and Wirthington's Sir John	6.32	23.8	72.86	44.75	28.11
Scotch Coals	Wallsend Elgin	8.46	29.1	76.09	47.75	28.34
	Wellewood	8.24	28.5	81.36	56.26	25.10
	Dalkeith Coronation Seam	7.71	24.5	76.94	50.40	26.54
	Kilmarnock Skerrington	7.66	30.3	79.82	48.05	31.77
	Fordel Splint	7.56	29.0	79.58	48.03	31.55
	Grangemouth	7.40	28.5	79.85	53.08	26.77
	Eglinton	7.37	24.3	80.08	52.50	27.58
	Dalkeith Jewel Seam	7.08	26.4	74.55	45.43	29.12
	Slievardagh Irish Anthracite	9.85	30.1	80 03		
Various	Coleshill Co.'s Bagillt Main	8.33	26.1	88.48	54.18	34.30
	Ewloe	7.02	31.1	80.97	50.87	30.10
	Ibstock	6 91	25.1	74.97	44.81	30.16
	Sydney (Forest of Dean)	8.52	26.0			
	Conception Bay, Chili	5.72	25.8			
Patent Coals	Warlich's Patent Fuel	10.36	31.5	90.02		
	Livingstone's Steam Fuel	10.03	32.5	86 07		
	Lyon's Patent Fuel	9.58	31.4	86.36		
	Wylam's	8.92	28.8	79.91	60.96	18.95
	Bell's	8.53	28.5	87.88	66.74	21.14
	Holland and Green's	7.59	23.7	70.14		

If the average quantities of steam raised by coals which are capable of reducing the same amount of lead, be now compared, as shown in Table III.,

TABLE III.

Lead reduced by 1 Part of Coal.	Steam generated by 1 Part of Coal.									
	Average Number of Specimens.	Welsh Coals.	Average Number of Specimens.	Newcastle Coals.	Average Number of Specimens.	Derbyshire Coals.	Average Number of Specimens.	Lancashire Coals.	Average Number of Specimens.	Scotch Coals.
Above 34	4	9.58								
33–34	5	9.75								
32–33	6	9.65	—	—	—	—	1	9.47		
31–32	9	9.02	6	8.88	1	7.92	1	8.17		
30–31	5	9.07	4	7.84	3	8.08	3	8.19	1	7.66
29–30	2	8.13	2	7.69	2	7.19	9	8.32	2	8.00
28–29	3	8.72	3	7.80	2	7.07	8	7.88	2	7.82
27–28	—	—	—	—	—	—	2	7.08		
26–27	2	8.42	1	6.82	—	—	3	7.54	1	7.08
25–26	—	—	1	7.30						
24–25	1	7.53	—	—	—	—	—	—	2	7.58
23–24	—	—	—	—	—	—	1	6.32		

it will be observed that although on the whole the amount of lead may be taken as an approximative test of the value of fuel, it can by no means be relied on as an exact measure of that value.

The same may be observed with reference to the amount of fixed carbon as shown in Table IV. for differences of 5 per cent.

TABLE IV.

Percentage of Coke.	Steam generated by 1 Part of Coal.									
	Average Number of Specimens.	Welsh Coals.	Average Number of Specimens.	Newcastle Coals.	Average Number of Specimens.	Derbyshire Coals.	Average Number of Specimens.	Lancashire Coals.	Average Number of Specimens.	Scotch Coals.
Above 90										
80–85	9	9.74								
75–80	6	9.43								
70–75	2	9.52	1	9.95						
65–70	2	9.34	1	9.38						
60–65	5	8.95	3	8.81	—	—	2	8.68		
55–60	2	8.42	7	7.46	—	7.94	10	8.09	1	8.24
50–55	4	8.28	3	7.52	5	7.34	10	7.99	3	7.49
45–50	2	7.71	—	—	2	—	4	7 81	4	7.69
40–45	—	—	—	—	—	—	2	7.02		
30–35	—	—	1	7.77						

The total amounts of carbon contained in the different coals classed together for every 5 per cent. of difference, and an average taken of the amount of steam raised from these, is shown in Table V., which, although it bears out the general fact of the carbon being in proportion to the steam raised, does not warrant the carbon being made an exact measure of the heating power.

TABLE V.

Total Percentage of Carbon.	Steam generated by 1 Part of Coal.									
	Average Number of Specimens.	Welsh Coals.	Average Number of Specimens.	Newcastle Coals.	Average Number of Specimens.	Derbyshire Coals.	Average Number of Specimens.	Lancashire Coals.	Average Number of Specimens.	Scotch Coals.
Above 90	3	10.12								
85–90	15	9.57	3	8.92						
80–85	6	9.19	14	7.84	4	8.10	9	9.39	2	7.80
75–80	7	8.39	1	7.71	3	7.31	14	7.92	5	7.96
70–75	3	8.25	—	—	—	—	4	7.26	1	7.08

The Hessian Society for the Promotion of Arts and Manufactures examined experimentally the value of wood, peat, and coal burnt under six different well-arranged coppers, and found that 1 lb. of cleft beech wood, two years felled, converted 2.075 lbs. of water from 0° C. into vapour, 1 lb. of peat evaporated 1.991 lb., and 1 lb. of small coal 5.201 lbs. of water.

The following information regarding trials of Russian coal is copied from "Engineering" of April 30, 1886:—

"Coal Experiments in the Pacific.—Some prolonged experiments with Pacific coal of various kinds, conducted by the naval authorities at Vladivostock, have yielded results of a very unsatisfactory character to Russia. The samples employed were obtained from the coal mines of Doue, on the island of Saghalien, from some newly-discovered deposits in the province of the Amoor, from the adjacent country of Corea, and from the immediate neighbourhood of Vladivostock. Cardiff coal, as at present used by the Russian Pacific fleet, was accepted as the standard, and the question confided to the commission to solve was, whether any of the rival sorts obtained in the Pacific were sufficiently good to permit of Russia dispensing with the further use of the English article. The trials were very carefully conducted, and, according to the newspaper *Vladivostock*, the commission pronounced all the coals to be too smoky, and expressed the belief that for the present the Russian Pacific fleet could not do without Cardiff coal. This decision is very disappointing to those who had pinned their faith on the Saghalien coal mines, and is not very agreeable to the Russian Government. In 1878, when war between England and Russia seemed probable, the Russians, in default of supplies of their own, had to purchase at any price all the coal they could lay their hands on in Japan, at San Francisco, in Australia, and elsewhere, and after all their exertions, were able only to concentrate a very inadequate quantity at Vladivostock. Taught by experience, the Government set to work, as soon as the Treaty of Berlin was signed, to develop the coal deposits in Saghalien, an island which Russia had recently seized from Japan on account of its known supply of fuel. To Saghalien since then about 5000 exiles and 1000 troops have been sent, and probably the sum expended in settling them there and opening up the mines, which are further protected by batteries, has not been much under a million sterling. In spite of this outlay, when, last spring, the English authorities bought up all the available Japanese coal, Russia again found herself provided with a limited stock of fuel, and that for the most part of an inferior quality. This has led to fresh activity in obtaining coal in the Amoor region and from Corea, but the outcome after all is that Russia finds herself compelled to continue her dependence upon Cardiff. Such a result is discouraging, even though the Vladivostock

authorities consider that the Pacific coal is less to blame than the incapacity of the Russian mining engineers to work the proper kind of coal and send it in a fit condition to the market. When Donetz coal was first extracted in South Russia the same objections were expressed to its quality, yet the industry has annually increased year after year, and the quality is rapidly improving. In all likelihood, the same will be the ultimate result in the Pacific."

By means of evaporative trials of various kinds of steam boilers, information has been from time to time collected as to the practical value of fuel.

In 1858, the Industrial Society of Mulhouse instituted some trials which were carried out with different designs of boilers worked under similar conditions. The results were reported upon by Messrs. Burnat and Dubied, who made careful investigations of the questions connected with the combustion of the fuel, as far as this could be done with the instruments for physical research which they had at command. Unfortunately, these results are not of much value, because they were not accompanied by analyses of the waste gases. They were also imperfect as regards measurement of the air supply used for combustion, and, in endeavouring to account for the utilization of the heat produced by combustion of the fuel, they exhibited a deficit of 20 per cent. The heat of combustion of coal had not been accurately determined at the date of these trials, so that Messrs. Burnat and Dubied were guided by Dulong's law, and by his figures of the calorific power of carbon and hydrogen.

Scheurer-Kestner began to investigate the subject in 1868, and has continued his investigations down to the present day. A *résumé* of his researches was given by him in a paper read before the Société Chimique of Paris, and is published in the *Revue Scientifique* of February 18, 1888. The following particulars are quoted from the abstract of that paper in the Journal of the Society of Chemical Industry (September 1888, p. 615).

Realizing that Burnat and Dubied's deficit of 20 per cent. "might proceed either from heat having in some way escaped unnoticed, or from an overestimation of the heat of combustion of the coal, he made a threefold division of the problem, and set himself first to ascertain the quantity and composition of the products of combustion; secondly, to determine accurately the heat of combustion of coal; and thirdly, to repeat the experiments of Messrs. Burnat and Dubied, following their method, but with such modifications as might be suggested by the study of the composition of the gaseous products of combustion.

"The composition of the gases arising from the combustion of coal had been studied before 1868 by men, like Ebelmen, whose names give a sufficient guarantee for the accuracy of their analytical results, but unfortunately the manner in which their samples were drawn precludes our attaching much importance to their work. Péclet, the first in this field, contented himself with reversing a flask filled with water in the gaseous current. Ebelmen's experiments were as imperfectly conducted, though this remark does not apply to his researches upon blast-furnace gases, which are much more uniform in composition. No more reliable are the experiments of Sauvages, whose samples were taken during some minutes from the grate of a locomotive in motion; nor those of Comines de Marsilly, whose sampling did not extend beyond a few seconds; nor those of M. Debette, quoted by M. Combes in his report on the means of consuming or preventing smoke. It is of vital importance that the sample operated upon should be thoroughly representative of the gases under investigation, and to this end the fire should be in operation at least a day before the conditions may be considered normal. It is also necessary that a large number of samples should be taken, or else (which is preferable) that the drawing should be a continuous one."

In Scheurer-Kestner's investigations, a point in the chimney flue was chosen for the taking of samples in order to obtain the gases as well mixed as possible, and because Cailletet had shown that the gases in the immediate neighbourhood of the fire exist in a state of dissociation. The method of sampling adopted was as follows:—"A column of 10 metres of water, 3 centimetres in diameter, was employed to aspirate a considerable quantity of gas from the flue, and from this current on its way from the flue to the aspirator, a second sample was drawn into a glass gas-holder containing several litres of mercury." The drawing of samples extended over the whole period of an investigation.

The fact having been established by earlier research that combustible gases, such as carbonic oxide, hydrocarbons, and hydrogen, always exist in the products of combustion even in presence of an excess of oxygen, Scheurer-Kestner showed that the amount of the excess of oxygen governs the proportion of combustible gases present. Some of the old analyses are considered by him to be worthless, because they sometimes show an excess of both oxygen and combustible gases present together, and sometimes a deficiency of both.

Scheurer-Kestner made an exhaustive series of experiments to determine the most advantageous proportions in which air should be admitted. "When Ronchamp coal was supplied with 8 to 9 cubic metres of air per kilo., the combustible gases escaping unconsumed amounted to from 6 to 18 per cent. of the carbon in the coal. With 10 to 12 cubic metres, the loss fell to 4 to 6 per cent.; and with 15 cubic metres it was only 1 to 1½ per cent. The net result of these experiments led to the conclusion that an excess of air should be employed amounting to about 50 per cent. of the quantity theoretically required. To ascertain the loss occasioned by smoke, a measured quantity of the gas was aspirated through a glass tube lightly packed with asbestos for a length of 25 to 30 millimetres. This filtering apparatus was placed side by side with the tube through which was passed the sample for analysis. The black discoloration, which did not penetrate more than 5 to 6 mm. into the asbestos, consisted of carbon and hydrocarbons, which latter imparted to it a tarry consistency. The quantity was determined by combustion and subsequent weighing of the carbonic acid formed." Even when a thick black smoke was purposely produced by limiting the air supply, the loss of heating effect due to smoke formation only amounted to 1½ per cent., and an increase of air reduced this to ½ per cent.

"Smoke is formed in two ways. Berthelot has shown that certain hydrocarbons when heated to suitable temperatures are decomposed with formation of a new hydrocarbon and deposition of solid carbon. This takes place on the grate where combustion is going on." The second way is by the dissociation of hydrocarbon gases due to cooling. This is shown by an experiment of Deville's. A curved copper tube is introduced into the gaseous current just behind the fire-bridge, both ends of the tube projecting outwards. When this tube is kept empty it soon attains the temperature of the gases at that point, and when withdrawn shows a coating of cupric and cuprous oxides according as the gases have been more or less oxidizing or reducing. When, however, water is allowed to circulate through the tube so quickly as to keep it cool, then it is thickly coated with smoke-black produced from the dissociation of the gases.

"The volume of air passing through the grate was calculated from the composition of the products of combustion, the following formula being used:—

$$V = \left[\frac{C}{0.000536\,V'} \left(V' + \frac{V''}{2} + V''' \right) + \frac{8\left(H - \frac{O-S}{8}\right)}{0.001437} \right] 4.761.$$

where V represents the volume of air employed per kilo. of coal burned,
C, O, H, S = respectively the carbon, oxygen, hydrogen, and sulphur in grammes per kilo. of coal burnt.
0.000536, V′, V″, V‴ represent respectively the carbon, carbonic acid, carbonic oxide, and oxygen contained per litre of the products of combustion,
8 = the equivalent of oxygen,
0.001437 = the weight of a cubic centimetre of oxygen,
4.761 = the proportion by volume existing between air and the amount of oxygen it contains.

Only the pure coal actually burned was taken into consideration, the necessary deductions being made for ashes, &c., passing through the fire-bars."

In conjunction with M. Meunier-Dollfus, researches were carried out on a variety of specimens of coal in order to establish some relation between the nature of the coal and the gaseous products of combustion. The results did not differ much from those obtained with Ronchamp coal. Investigations were also made to determine the calorific value of coal, as Dulong's estimate of the average heat of combustion of coal at 7,600 calories was not considered wholly satisfactory. In the case of the determinations made by Scheurer-Kestner and Meunier-Dollfus, "the samples operated upon were obtained by repeated subdivisions of the bulks of coal actually used at the boiler fire, and as finally obtained consisted of about 10 grammes each, in the state of fine powder. The representative character of these samples was established by the close agreement between the percentages of ash yielded by them and the weights of ash actually obtained from the boiler ash-pits." The calorimeter of Favre and Silbermann was used in these investigations, but with some modifications rendered necessary by the fineness of the samples and their very small bulk—not more than 5 or 6 decigrams having been experimented on at one time.

In consequence of the very small rise of temperature produced in the calorimeter bath by the combustion of such small quantities, a special thermometer was made by M. Baudin for these experiments.

"It contained 63 grammes of mercury; each degree occupied a length of 36 millimetres on the scale, and was divided into fifty parts, but could be read to a five-hundredth. This instrument was also on Walferdin's metastatic principle, serving for all ranges of temperature, though its stem only comprised 10° C." Scheurer-Kestner also found that, "as was stated by Mulder, soda-lime was very much superior to potash as an absorbent for the gases produced by combustion."

"From these experiments it was seen that the heats of combustion of different coals varied considerably, sometimes exceeding the values found by calculation, and sometimes (but more rarely) falling short of them. Generally speaking, however, bituminous coals gave higher results and a larger volume of gaseous products of combustion than non-bituminous. The bituminous coal of Creusot gave 9,620 calories; the non-bituminous coal from Louisenthal in the Saarbrück district gave only 8,215. With the exception of a Russian coal, which fell even below that of Louisenthal, these were the two extremes, the yield in most cases lying between 8,500 and 8,700 calories. It was found to be impossible to determine the calorific power of any coal with certainty save by actual experiment, as it almost always exceeds that obtained by following Dulong's law, and often exceeds the addition of the calorific powers of the total carbon and hydrogen present."

The theory of M. Cornut, engineer of the Société des Appareils-à-vapeur of Lille (referred to p. 709, *ante*), was applied to Scheurer-Kestner's results, and gave indications of its being "a means of arriving at the calorific power by calculation much more approximately than is possible by the use of

Dulong's law. If the heats of combustion of the two kinds of carbon and of the hydrogen be added together and the oxygen disregarded, the error rarely exceeds 5 per cent. In proof of this may be cited the fact that the heats of combustion of twenty coals from the North of France were determined by actual experiment, and compared with the figures obtained by using M. Cornut's formula. In four cases the agreement was perfect, in seven there was a discrepancy of 1 to 2 per cent., and in six a discrepancy of 3 to 6 per cent., whilst in three the difference rose to 8 to 11 per cent."

A table giving all the results of these investigations from 1868 to 1874 is published in the *Bulletin de la Société Industrielle de Mulhouse* of June 1875, and the following abstract is due to D. K. Clark.* He says the authors state that, since the commencement of their labours, Messrs. Jamin and Amaury had demonstrated that the specific heat of water varies sensibly between the temperatures at which their trials were made; and that the employment of the formula of these experimenters would augment by about 2 per cent. the tabulated quantities of the heats of combustion.

All the numbers in the table have reference to the substance dry and pure—that is, to the combustible dried at 212° F. and free from ash.

ANALYSES OF FRENCH AND OTHER COALS AND LIGNITES, AND THE OBSERVED HEATS OF COMBUSTION.

Name of Combustible.	Elements.			Heat of Combustion of 1 lb. of Pure Fuel. English Units.
	Carbon.	Hydrogen.	Oxygen and Nitrogen.	
Coal.	per cent.	per cent.	per cent.	
Ronchamp, 3 samples	88.59	4.69	6.72	16,416
Saarbrücken, 7 „	81.10	4.75	14.15	15,320
Creusot, 4 „	90.60	4.10	5.30	16,994
Blanzy, Montceau	78.58	5.23	16.19	14,985
„ anthracitic	87.02	4.72	8.26	16,400
Anzin	84.45	4.21	11.32	16,663
Devain	83.94	4.43	11.63	16,290
English, Bwlf	91.08	3.83	5.09	15,804
„ Powell-Duffryn	92.49	4 04	3.47	16,108
Russian, Groucheffski, anthracitic	96.66	1.35	1.99	14,866
„ Miouchi, bituminous	91.45	4.50	4 05	15,651
„ Golouboffski, flaming	82.67	5.07	12.26	14,438
Lignite.				
Rocher bleu	72.98	4.04	22.98	11,670
Manosque, bituminous	70.57	5.44	23.99	13,253
„ dry	66.31	4.85	28.84	12,584
Bohemian, bituminous	76.58	8.27	15.15	14,263
Russian, Toula	73.72	6.09	20.19	13,837
Lignite passing to fossil wood	66.51	4.72	28.77	11,444
Fossil wood passing to lignite	67.60	4.55	27.85	11,360

Scheurer-Kestner repeated the experiments of Burnat and Dubied on the large scale, but estimated the volume of air used in combustion from the composition of the escaping gases, instead of by means of anemometer readings of the velocity of the inflow of air caused by draught.

The boiler used by him was of "the kind common in Alsace, three-tubed, externally fired, and provided with a feed-water heater." This kind of boiler is also called the "French" and the "elephant" boiler.

In spite of precautions against the unobserved escape of heat, the experiments made in 1868 showed a deficit ranging from 21 to 27 per

* "Min. Proc. Inst. C.E.," vol. xliii. p. 396.

cent. In the case of Ronchamp coal the calories were distributed as follows:—

	Per cent.
As steam	63.6
In chimney gases	5.1
As combustible gases escaping	4.9
As smoke	0.0
As water vapour in the smoke	3.0
Not traced	23.0
	100.0

"Since that time, the feed-water heater has been changed for another of improved construction. The old one consisted of six cylinders placed two by two in a brickwork setting, and the feed water, traversing these, acquired a temperature corresponding to 8 per cent. of the total calories generated. With the new heater, which was on the tubular systen, the efficiency rose to 12 per cent.

"An experiment made three years ago on a coal from the Ruhr gave the following results:—

	Per cent.
Calories converted into steam	67.3
„ traced in products of combustion	11.6
	78.9

"In a recent trial of an English coal of exceptional quality, almost smokeless, and giving only traces of combustible gases, steam was raised equal to 74.5 per cent. of the total calories generated, and the deficit was reduced to 17 per cent. To get some idea of the direction of this loss it was suggested by an English engineer, Mr. Donkin, that the boiler should be put and kept under pressure for a given time, account being taken of the quantity of fuel required to maintain the *status quô*, all outlets being closed. This experiment was carried out over several days and nights, and led to the conclusion that the loss by radiation from the boiler alone was about 4.6 per cent. Of the remaining 12 per cent. it is believed that almost the whole may be accounted for by external radiation. The return of steam was found to vary by from 8 to 10 per cent. according as the experiment was carried out in summer or winter. This fact was established by repeated experiments with different kinds of coal. Now, if the difference of temperature between summer and winter can cause this variation (equal to about 7 per cent. of the total calories), it may fairly be inferred that, if we could estimate the loss resulting from the constant contact of the brickwork with the surrounding air, we should not fall far short of the total number of calories to be accounted for."

The Industrial Society of Mulhouse* resolved in 1874 to make comparative trials with a Lancashire boiler, a French or elephant boiler, and a Fairbairn boiler. These trials were carefully carried out, and, although primarily of value in connection with questions of boiler design, give some information as to the evaporative effect of certain French and German coals when used on the large scale.

The dimensions and general proportions of the boilers are given in the Society's Journal and by Mr. D. K. Clark.† The products of combustion in the Lancashire boiler passed from the inside flues on each side to the front and thence under the boiler to the chimney. In the Fairbairn boiler, they passed from the flues by the sides of the lower cylinders, and returned by the sides of the upper cylinder towards the chimney. In the French boiler, the current was not divided, but after heating the

* *Bulletin de la Soc. Indust. de Mulhouse*, June 1875, pp. 241–272.

† See "Min. Proc. Inst. C.E.," vol. xliii. p. 377; "Manual of Rules, Tables, and Data," third edition, p. 797.

three heaters it wound round the boiler. The flues delivered into the same chimney. The temperature in the flues, just at the chimney about 4 inches above the bottom, was taken every five minutes by means of the nitrogen-thermometer of MM. Hirn and Hallauer.* The products of combustion were analysed by means of Orsat's apparatus.†

The feed water was taken from the condenser of a neighbouring engine, and the temperature varied from 79° to 84° F. The quantity of water was ascertained by a measuring vessel, from which it was drawn with regularity by a donkey pump. The measurement of priming water was effected by Hirn's process. The mean pressure of steam was maintained at from 4½ to 5 atmospheres, the steam being employed to drive two Woolf engines.

Three series of trials were made: with best Ronchamp coal heavily fired; the same lightly fired; and with best Von der Heyt coal from the Saarbrücken district. For each boiler a preliminary trial, lasting two days, was made, in order to settle the conditions in the official trials. The coal consumed in getting up steam was included in the consumption. Two days before the trial each boiler was emptied and thoroughly cleaned inside and outside, and the evening before the trial steam was got up. In the first series of trials, with Ronchamp coal heavily fired, each boiler was tried for six days. The regular daily work was performed; the charging of fuel was commenced at 5.15 A.M., when the pressure was got up, and the engine started about 6 A.M.; there was a pause at noon for 1¼ hour, after which the engine was again started and worked till 6 P.M.

For the second and third series of trials, each boiler was worked for three days. An extra three days' trial of the Lancashire boiler was made with Ronchamp coal, to try the effect of increasing the supply of air, and this made up nine days' trial of that boiler.

The general evaporative results are given in the following table:—

Boilers and Fuel.	Coal consumed per Hour.			Water evaporated per Hour from and at 212° F.		Water per lb. of Entire Coal.	Temperature of Gases.	Air drawn in per lb. of Coal.
	Total.	Per Square Foot of Grate.	Ash.	Total.	Per Square Foot of Grate.			
Ronchamp coal: Heavy firing—	cwts.	lbs.	per cent.	cub. ft.	cub. ft.	lbs.	F.	cub. ft.
Fairbairn boiler	3.39	18.53	13.8	56.06	2.73	9.21	421°	226
Lancashire „	3.50	19.15	14.1	53.45	2.61	8.50	572	183
French „	3.69	20.57	14.1	54.73	2.72	8.26	562	194
Ronchamp coal: Light firing—								
Fairbairn boiler	1.96	10.70	13.5	31.14	1.52	8.86	337	261
Lancashire „	1.91	10.41	14.6	30.52	1.49	8.92	406	194
French „	2.04	11.36	13.6	31.38	1.56	8.58	425	193
Saarbrücken coal—								
Fairbairn boiler	3.04	16.59	10.6	43.20	2.11	7.93	402	195
Lancashire „	3.02	16.50	9.7	40.69	1.99	7.51	554	180
French „	3.11	17.32	9.4	41.89	2.08	7.51	544	179
General averages of the above—								
Fairbairn boiler	2.80	15.27	12.6	43.74	2.12	8.67	387	227
Lancashire „	2.81	15.35	12.8	41.55	2.03	8.33	511	186
French „	2.95	16.42	12.4	42.67	2.12	8.12	510	189
Averages of three days' performance when equal rates of evaporation were effected—								
Lancashire boiler	3.57	19.50	—	54.10	2.64	8.44	587	165
French „	3.57	19.87	—	54.32	2.70	8.49	572	197

* Vide *Bulletin de la Soc. Indust. de Mulhouse*, 1869, p. 543; 1873, p. 257; 1874, p. 421.
† *Ibid.*, 1874, p. 421.

In Britain and America, many experiments have been made with steam boilers in order either to determine the proportional evaporative value of different portions of the heating surface; or to ascertain the relations of grate area, heating surface, water, and fuel; or to test the evaporative values of various kinds of coal, and the relative advantages of different methods of firing. The result of this experimental work has been improvement in boiler design and working, and undoubted advancement in understanding various questions connected with the combustion of fuel.

Experiments with locomotive boilers were made by Messrs. E Woods and J. Dewrance* in 1842, and by Mr. D. K. Clark† in 1852, and previous years, the latter of whom submitted his own results and those of others to an elaborate analysis for the purpose of arriving at formulæ expressive of the relation of coal and water consumed in steam boilers per square foot of grate area per hour, and the ratio of the heating surface of the boiler to the area of the fire-grate. These formulæ were approved of by Rankine and others, but criticized adversely by Mr. Longridge‡ and some others, who have advanced some useful considerations on the subject. Some ingenious ideas on the evaporation in steam boilers were also announced by M. Paul Havrez,§ and useful results have been published by Mr. L. E. Fletcher,‖ Sir Henry De la Bèche and Dr. Lyon Playfair,¶ Messrs. Longridge, Armstrong, and Richardson,** and by Messrs. Miller and Taplin†† for the British Admiralty. Results have also been collected in America by Prof. W. R. Johnson,‡‡ Mr. B. F. Isherwood,§§ and by Prof. Thurston and the judges at the Philadelphia and other Exhibitions.‖‖ Some interesting results are also contained in the Transactions of the Literary and Philosophical Society of Manchester (vol. xv., 1858), and in those of the Royal Agricultural Society of England (report on the trials of portable steam engines at Cardiff, by the judges, 1872).

Reference may also be made to a paper by Prof. R. Werner in *Zeitschrift des Vereines deutscher Ingenieure* (1883, pp. 394-398) and Trans. N. of England Inst. M. Eng. (vol. xxxiii. p. 77 of abstracts).

It is impossible within the limits of this work to do more than illustrate a few of the results obtained by some of these investigators.

Mr. Clark published a table containing particulars of the performance and proportions of fifty-two coke-burning locomotive engines, or classes of engines, made with areas of fire-grate of from 6 to 24 feet. In nearly every instance the recorded performances were the average results of several trips, comprising altogether upwards of three hundred trips. From these results he constructed a formula of general application; but, inasmuch as it is not now the practice to any extent to employ coke as the fuel in locomotives, the table need not be reproduced here. Regarding the deductions from it, Mr. Clark said, "It was well known that in any given boiler in which the grate

* See "The Engineer," March 1858.

† "Railway Machinery," by D. K. Clark; also Experimental Investigation of the Principles of Locomotive Engines: "Min. Proc. Inst. C.E.," vol. xii. pp. 382-449; *ibid.*, vol. xlvi. p. 242; "Manual of Rules, Tables, and Data," third edition, pp. 768-821.

‡ See "Min. Proc. Inst. C.E.," vol. lii. pp. 98-175.

§ Evaporation in Steam Boilers decreasing in Geometrical Progression, by M. Paul Havrez: see *Annales du Génie Civil*, Aug. and Sept. 1874; also "Min. Proc. Inst. C.E.," vol. xxxix. p. 378.

‖ The South Lancashire and Cheshire Coal Association's Report on the Boiler and Smoke Prevention Trials conducted at Wigan in 1869.

¶ Government Reports on Coals, 1849, 1850, 1851.

** Report to the Steam Collieries Association of Newcastle-on-Tyne, 1857.

†† Reports to the Admiralty, 1858 and 1863.

‡‡ A Report to the Navy Department of the United States on American Coals, 1844.

§§ "Experimental Researches in Steam Engineering," vol. ii., 1865.

‖‖ See "Engineering," vol. xiii.; also vols. for 1875, 1877, &c.; also Report of Committee on Test of Steam Boilers, "Trans. American Inst.," 1871-72; also Prof. R. H. Thurston in "Trans. Amer. Society of Engineers," 1874.

COMPARATIVE EVAPORATIVE RESULTS OBTAINED FROM STATIONARY BOILERS AT WIGAN, WITH HINDLEY YARD COAL—1867–68.

I. *Averages of Sixty Trials.*

Boilers and Mode of Firing.	Area of Fire-grate.	Coal consumed per Week of 60 Hours.	Coal consumed per Hour.	Coal per sq. ft. of Grate per Hour.	Water consumed from 100° per Hour.	Water per sq. ft. of Grate per Hour.	Water evaporated from 212° per lb. of Coal.	Smoke per Hour.
ROUND COAL, COKING FIRING, 12 ins. thick, WITHOUT ECONOMIZER.	sq. ft.	tons.	cwts.	lbs.	cub. ft.	cub. ft.	lbs.	minutes.
Lancashire boiler with iron tubes	31.5	15.69	5.23	18.60	86.73	2.75	10.32	very light 2.9, brown 1.2, black 0.7
„ „ steel „	„	16.15	5.38	19.10	87.74	2.79	10.17	„ 1.5 „ 0.2 „ 0.0
Galloway boiler	„	15.43	5.15	18.30	84.21	2.67	10.19	„ 2.1 „ 1.2 „ 0.5
Lancashire boiler with iron tubes	21.0	12.13	4.04	21.50	70.62	3.36	10.88	„ 0.3 „ 0.0 „ 0.0
„ „ steel „	„	12.75	4.25	22.70	73.40	3 50	10.77	„ 4.5 „ 0.0 „ 0.0
Galloway boiler	„	12.23	4.08	21.80	70.52	3 36	10.77	„ 4.7 „ 0.1 „ 0.0
SPREADING FIRING, 12 ins. thick.								
Lancashire boiler with iron tubes	31.5	16.92	5.64	20.10	86.77	2.75	9.56	„ 5.3 „ 4.9 „ 3.3
„ „ steel „	„	no trials						
Galloway boiler	„	16.84	5.61	20.00	87.98	2 80	9.75	„ 4.4 „ 3.6 „ 2.8
Lancashire boiler with iron tubes	21.0	12.11	4.04	21.60	71.44	3.40	10.62	„ 13.7 „ 3.4 „ 2.5
„ „ steel „	„	12.93	4.31	23.00	73.72	3.51	10.60	„ 14.5 „ 3.3 „ 1.9
Galloway boiler	„	12.79	4.26	22.70	73.10	3.48	10.66	„ 14.1 „ 4.7 „ 1.8
AVERAGES.								
Lancashire boiler with iron tubes	—	14.21	4.74	20.50	78.89	3.06	10.34	„ 5.6 „ 2.4 „ 1.6
„ „ steel „	—	14.69	4.90	21.60	80.41	3.27	10.28	„ 6.4 „ 2.1 „ 1.3
Galloway boiler	—	14.31	4.77	20.70	78.95	3.08	10.34	„ 6.3 „ 2.4 „ 1.3
Average of the three boilers	—	14.40	4.80	20.90	79.40	3.14	10.32	„ 6.1 „ 2.3 „ 1.4

II. *Best Results obtained from the Three Stationary Boilers.*

ROUND COAL, COKING FIRING, 12 ins. thick, WITHOUT ECONOMIZER.								
Lancashire boiler with iron tubes . . .	31.5	16.47	5.49	19.52	92.07	2.92	10.43	very light 2.7, brown 0.9, black 0.0
„ „ steel „ . . .	„	14.90	4.97	17.67	84.65	2.69	10.62	„ 0.5 „ 0.0 „ 0.0
Galloway boiler	„	16.00	5.33	18.95	85.22	2.71	9.95	„ 0.0 „ 0.0 „ 0.0
Lancashire boiler with iron tubes . . .	21.0	12.14	4.05	21.60	73.12	3.48	11.22	„ 0.9 „ 0.0 „ 0.0
„ „ steel „ . . .	„	12.91	4.30	22.93	77.84	3.71	11 22	„ 4.2 „ 0.0 „ 0.0
Galloway boiler	„	12.14	4.05	21.60	73.12	3.48	11.22	„ 6.3 „ 0.0 „ 0.0
Means of the Two Sizes of Grates.								
Lancashire boiler with iron tubes . . .	—	14.31	4.77	20.39	82.59	3.20	10.82	„ 1.8 „ 0.4 „ 0.0
„ „ steel „ . . .	—	13.91	4.64	19.79	81.24	3.20	10.91	„ 2.3 „ 0.0 „ 0.0
Galloway boiler	—	14.07	4.69	20.05	79.17	3.10	10.58	„ 1.3 „ 0.0 „ 0.0
Average of the three boilers . . .	—	14.10	4.70	20.05	81.00	3.09	10.77	„ 1 8 „ 0.1 „ 0.0
WITH ECONOMIZER.								
Lancashire boiler with iron tubes . . .	31.5	17.57	5.86	20 84	107.78	3.42	11.46	„ 3.2 „ 1.3 „ 0.0
„ „ steel „ . . .	„	14.27	4.76	16.92	88.02	2.79	11.51	„ 1.6 „ 0.0 „ 0.0
Galloway boiler	„	15.53	5.18	18.42	97.98	3.11	11.78	„ 6.5 „ 0.5 „ 0.0
Lancashire boiler with iron tubes . . .	21.0	no trials						
„ „ steel „ . . .	„	13.39	4.46	23.79	83.54	3.98	11.65	„ 0.6 „ 0.0 „ 0.0
Galloway boiler	„	11.75	3.92	20.91	74.73	3.56	11.86	„ 0.7 „ 0.6 „ 0.0
Means of the Two Sizes of Grates.								
Lancashire boiler with iron tubes . . .	—	15.48	5.16	22.06	95.66	3.65	11.56	„ 1 9 „ 0.7 „ 0.0
steel „ . . .	—	13.83	4.61	19.22	85.78	3.39	11.57	„ 1.1 „ 0.0 „ 0.0
Galloway boiler . . .	—	13.64	4.55	19 45	86.31	3.33	11.82	„ 3.6 „ 0.5 „ 0.0
Average of the three boilers . . .	—	14.32	4.77	20.39	89.25	3.40	11.65	„ 2.2 „ 0.4 „ 0.0

area and the heating surface were constant, and of course also the ratio of these areas, the greater the quantity of fuel consumed per hour the greater also was the quantity of water evaporated; but that the production of steam increased at a less rate than the combustion of fuel; in other words, that the quantity of water evaporated per lb. of fuel diminished. The question had, however, remained, At what rate did this diminution of efficiency take place? The answer was supplied by the fact, generalized from experimental observations on stationary, portable, marine, and locomotive boilers, that the quantity of water, w, evaporated per square foot of grate was expressed by a constant quantity A, plus a constant multiple Bc, of the fuel c, consumed per square foot of grate; according to the general equation,

$$w = A + Bc.$$

"The sense of this equation was, that whilst the proportion of the water evaporated per square foot of grate did not keep pace with the fuel consumed, yet the quantity of water increased by equal increments for equal increments of fuel per square foot of grate. The great principle of the formula was that, in maintaining constant evaporative efficiency of the fuel—that was, when the same proportion of water was evaporated per lb. of fuel, the total evaporative capacity of the boilers increased directly as the square of the heating surface and decreased directly as the area of the grate increased. As a consequence, the water evaporated per square foot of grate per hour under those conditions increased as the square of the surface ratio—that was, as the square of the ratio of the heating surface to the grate area. The general equation took the following form, embracing the two principles—

$$w = ar^2 + Bc,$$

or for locomotives burning coke—

$$w = .0178r^2 + 7.94c \text{ (coke)}.$$

c = the quantity of coke in lbs. per square foot of grate per hour.

w = the equivalent quantity of water evaporated in lbs. per square foot of grate per hour from and at 212° F.

r = the surface ratio, or ratio of the heating surface to grate area.

"With so many and varied proportions of heating surface to fire-grate area as were shown in the table—from a heating surface 6 times the grate to a surface 100 times the grate—it was necessary to reduce all the performances to the equivalents for one standard surface ratio in the proportion of the squares of the surface ratios, in order that they might be directly compared; and the standard ratio 1 to 75 had therefore been adopted for coke-burning locomotives."

The following table of examples, extracted from "Railway Machinery,"* shows how closely the evaporation proceeded according to the square of the surface ratio when 9 lbs. of water, at the ordinary temperatures and pressures, were evaporated per lb. of coke:—

RELATIVE HEATING SURFACES AND RATES OF CONSUMPTION IN LOCOMOTIVE BOILERS.

Classified Groups of Locomotives.	Surface Ratio.	Consumption of Water per Hour per Square Foot of Grate.	Water per lb. of Coke.	Number of Experiments.
	ratio.	cubic feet.	lbs.	
Orion, Sirius, Pallas, E. & G. Railway	52	6.15	9.00	13
C. R. passenger engines	66	8.00	9.10	17
Snake, L. & S. W. Railway	72	12.00	8.90	2
Sphynx, A, Hercules	90	18.00	8.92	8

* "Railway Machinery," p. 158.

The table on pp. 724, 725 gives evaporative results obtained by Mr. L. E. Fletcher in a series of trials with Lancashire and Galloway boilers of ordinary dimensions at Wigan in 1866–68, the fuel having been Hindley yard coal from Trafford Pit, considered one of the best coals in the district. The table was compiled by Mr. D. K. Clark from Mr. Fletcher's report, and gives the results of 60 out of about 290 trials made, these 60 being comparative trials; the second part gives the best results obtained from each boiler fired with round coal on the coking system, air being admitted through the door.

The following table gives the results obtained with different coals from South Lancashire and Cheshire employed in a marine boiler, which was a copy of the test-boiler at Keyham Dockyard; the total area of fire-grates was 10.3 square feet:—

Coal.	Coal consumed per Hour.	Coal per Square Foot of Grate per Hour.	Water consumed from 100° per Hour.	Water per Square Foot of Grate per Hour.	Water evaporated from 212° per lb. Coal.	Smoke per Hour.
	cwts.	lbs.	cub. ft.	cub. ft.	lbs.	minutes.
						Very light.
Hindley yard	2.32	25.24	46.17	4.48	12.39	0.2
Worsley top four-feet	2.88	31.36	48.50	3.04	10.37	4.0
Upper Crumbouke	2.64	28.74	48.13	4.67	11.31	5.3
Lower „	2.43	26.41	48.60	4.72	12.45	1.8
Upper three-yards	2.48	27.00	46.26	4.49	11.60	3.3
Six-feet rams	2.44	26.50	44.35	4.31	11.34	2.0
Great seven-feet	2.73	29.71	51.34	4.98	11.71	5.9
Blackrod yard	2.31	25.14	45.37	4.40	12.18	2.4
Pemberton four-feet	2.84	30.87	51.63	5.01	11.31	2.9
Haigh yard	2.35	25.53	47.38	4.60	12.54	0.5
Furnace Mine	2.66	28.93	44.49	4.32	10.40	1.4
Bickerstaffe four-feet	2.54	27.67	45.28	4.40	11.08	0.0
Rushy Park and Little Delf, mixed	2.80	30.29	50.67	4.92	11.29	4.3
Ince, mixed	2.63	28.64	46.52	4.51	10.99	1.6
Arley Mine	2.26	24.46	44.12	4.28	12.18	0.4
Average results of 15 samples of coal	2.55	27.63	47.25	4.59	11.54	2.4
Mixture of 2 Hindley yard coal and 1 Welsh coal-dust	2.21	24.00	41.38	4.02	11.83	0.0

The American coals analysed by Prof. W. R. Johnson were tried for evaporative performance in a small cylindrical boiler at the Navy-yard, Washington, in 1843, with the following results:—

RESULTS OF THE EVAPORATIVE PERFORMANCE OF AMERICAN COALS WITH A CYLINDRICAL STATIONARY BOILER, AT THE NAVY-YARD, WASHINGTON.

Coal.	Area of Fire-grate.	Coal consumed per Hour.	Coal per Square Foot of Grate per Hour.	Water evaporated from Ordinary Temperature per Hour.	Water per Square Foot of Grate per Hour.	Water evaporated from 212° F. per lb. Coal.
	sq. ft.	lbs.	lbs.	cub. ft.	cub. ft.	lbs.
Anthracites (7 samples)	14.30	94.94	6.64	12.37	0.87	9.63
Free-burning bituminous coals (11 samples)	14.14	99.16	7.01	13.73	0.97	9.68
Bituminous caking coals (Virginian, 10 samples)	14.15	105.02	7.42	12.16	0.86	8.48
Averages	14.20	99.71	7.02	12.75	0.90	9.26

Many reports of evaporative results possess great interest from an engineering point of view, as illustrating the comparative efficiency of different designs of boilers and the effects of different proportions of surface, &c. They are, however, unimportant as regards the present subject, in consequence of absence of information as to the fuel used.

The following table gives comparative results with Newcastle and Welsh coals :—

RESULTS OF EVAPORATIVE PERFORMANCE OF NEWCASTLE AND WELSH COALS IN THE COAL-TESTING MARINE BOILER AT KEYHAM STEAM FACTORY, 1863.

Coal.	Area of Fire-grate.	Coal consumed per Hour.	Coal per Square Foot of Grate per Hour.	Water consumed from 100° per Hour.	Water per Square Foot of Grate per Hour.	Water evaporated from 212° per lb. of Coal.
1st Series.—Coals in Store, recently delivered.	sq. ft.	cwts.	lbs.	cub. ft.	cub. ft.	lbs.
With common doors—						
Welsh — Waynes Merthyr, Resolven, Merthyr Dare, Gellia Cadoxton . .	14.0	1.93	15.44	32.4	2.31	10.42
Hartley Main, Newcastle	14.0	2.32	18.56	34.5	2.46	9.22
½ Welsh, ½ Hartley	14.0	1.92	15.40	30.4	2.17	9.81
2 „ 1 „	14.0	1.76	14.08	28.7	2.05	10.12
1 „ 2 „	14.0	1.96	15.70	30.7	2.20	9.72
With perforated door—						
Hartley Main	14.0	2.06	16.50	30.2	2.16	9.10
2nd Series.—Fresh Coals, specially ordered for trial.						
With common doors—						
Welsh—Powell's Duffryn, Nixon's navigation, Davis's Merthyr . . .	14.0	2.09	16.68	37.1	2.65	11.05
Newcastle — Davidson's Hartley, Hastings' Hartley	14.0	2.29	18.29	34.5	2.46	9.39
½ Welsh, ½ Hartleys	14.0	2.03	16.24	34.4	2.46	10.50
2 „ 1 „	14.0	2.43	16.36	35.0	2.50	10.61
1 „ 2 „	14.0	2.06	16.44	33.5	2.39	9.43
Welsh	14.0	2.19	17.48	39.3	2.80	11.16
3rd Series.						
With perforated doors—						
Welsh coal	14.0	1.87	14.95	32.7	2.34	10.86
Hartleys	14.0	2.13	17.04	32.8	2.34	9.61
½ Welsh, ½ Hartleys	14.0	2.18	17.44	37.1	2.65	10.54
2 „ 1 „	14.0	2.08	16.64	35.7	2.55	10.64
1 „ 2 „	14.0	2.18	17.42	36.5	2.61	10.39
Davidson's Hartley	14.0	2.86	22.88	42.9	3.06	9.31
½ Hartley, ½ Welsh	14.0	2.30	18.40	31.0	2.22	10.80
4th Series.—With Smaller Grate Area.						
With common doors—						
Welsh coal	10.5	2.11	22.46	38.3	3.65	11.31
½ Welsh small, ½ Davidson's Hartley .	10.5	2.02	21.6c	36.0	3.43	11.06
½ „ beans, ½ Hastings' „	10.5	2.14	22.85	36.7	3.50	10.65
5th Series.						
With perforated doors—						
Hartleys	10.5	2.29	24.40	42.0	4.00	11.42
½ Welsh, ½ Davidson's Hartley . .	10.5	2.10	22.34	39.3	3.74	11.65

RESULTS COMPILED FROM TABLES OF TRIALS OF PORTABLE ENGINES, ROYAL AGRICULTURAL SOCIETY, CARDIFF, 1872.

Boilers all Locomotive Type, except M, which was a Vertical Boiler with circulating Water Tubes. Fuel Llangennech (Welsh) Coal. Theoretical Evaporative Power from 60° = 13.2 lbs.

Different Examples of Agricultural Engines and Boilers.	Area of Fire-grate as used.	Total Heating Surface.	Ratio of Total Heating Surface to Area of Fire-grate used.	Total Evaporation per Hour from 60°.		Evaporation per Square Foot of Heating Surface.		Evaporation from 60° per lb. of Coal.		Evaporation per Hour per Foot of Fire-grate actually used.		Lbs. of Coal burnt per Hour per Square Foot of Fire-grate used.	Lbs. of Coal burnt per Hour per Square Foot of Heating Surface.	Temperature of Gases in Smoke Box.	Ratio of Duty obtained from the Coal as compared with its Theoretic Value.
	sq. ft.	sq. ft.		cu. ft.	lbs.	cu. ft.	lbs.	cu. ft	lbs.	cu. ft.	lbs.	lbs.	lbs.		
A	3.00	283.5	94	6.5	417	.022	1.4	.142	8.86	2.17	139	15.70	.16		.671
B	3.20	220.0	70	6.5	419	.030	1.9	.164	10.24	2.00	131	12.80	.18	360° to 418°	.776
C	3.20	220.0	70	6.3	409	.029	1.8	.164	10.23	1.99	129	12.50	.18	390° to 415°	.775
D	5.10	170.6	33	4.7	296	0.27	1.7	.063	3.93	0.92	58	14.80	.43	548°	.300
E	2.00	193.0	96	—	—	—	—	—	—	—	—	19.15	.50		
F	3.20	159.1	50	4.6	287	0.17	1.1	.151	9.43	1.46	90	9.53	.19	385°	.714
G	4.70	158.0	34	7.9	493	0.50	3.1	.127	8.08	1.61	105	13.00	.38	about 600°	.612
H	2.37	211.0	89	7.0	438	0.32	2.0	.145	9.08	2.53	185	20.40	.23	425° to 435°	.688
I	1.60	151.6	.94	—	—	—	—	—	—	—	—	35.10	.37		
J	3.50	187.8	54	10.0	622	0.52	3.3	.137	8.60	2.86	177	20.70	.38	500°	.651
K	5.00	129.8	26	8.3	522	0.51	3.2	.124	7.77	1.66	104	13.60	.52	over 600°	.588
L	2.00	204.5	102	8.0	499	.038	2.4	.128	8.03	4.00	249	31.10	.30	at end of run 360°	.608
M	3.75	168.4	45	5.9	370	.044	2.8	.152	9.54	1.71	100	10.30	.23	320° to 380°	.723

A very interesting record of evaporative results was given by Sir Frederick Bramwell,* as obtained by himself and Dr. Russell in 1873, with a vertical boiler with internal circulating pipes. The fuel used in this case was ordinary gas coke, which had absorbed 10 per cent. of moisture from exposure to the air, although it had been kept in a covered shed.

The plan of trial pursued was practically that adopted by the Royal Agricultural Society. Steam was got up and the boiler was worked for a short time with steam at 53 lbs., the water-level being normal. The hot fuel was then drawn out and weighed, and put back again with 10 lbs. of wood. The coke had been previously weighed out in parcels of 14 lbs. each, and the time of finishing each of these and each measure of water was duly noted. At the end of the trial, steam, water, and fire having been brought into the original condition, the fuel in the furnace was weighed. An anemometer was placed in the opening to the ash-pit in different parts to register the entering air. A thermometer was placed in the chimney and samples of the waste gases were analysed. The feed-water was weighed, and precautions were taken to test the steam for priming water. An ingenious method was also adopted for estimating the loss by radiation and convection from the boiler surfaces, and the results were arranged in the form of the following balance-sheet, to show at a glance the various elements of the experiment.

* "Min. Proc. Inst. C.E.,' vol. lii. p. 154.

BALANCE-SHEET, SHOWING RESULTS OF TRIAL.

Duration of Experiment, 4 hours 12 minutes.

Dr.	lbs.		lbs.	lbs.	Cr.
To gas coke	228.25	By water in coke	24.08		
„ wood	10.00	„ ash	10.33		
		„ hydrogen, oxygen, nitrogen and sulphur	3.42		
				37.83	
		„ water in wood	2.00		
		„ ash	0.20		
		„ hydrogen	0.49		
		„ oxygen	3.27		
				5.96	
					43.79
		Balance, being useful combustible			194.46
	238.25				238.25

	Heat units.		Heat units.
To balance of useful combustible brought down 194.46 × 14,000 (units of heat per lb. coal)	2,722,440	By 3,330 lbs. of air (being 17⅛ lbs. of air to 1 of carbon) raised from 60° to 700° (the temperature of the outgoing gases) 3,330 lbs. × 640° × .2379	506,880
		„ 26.08 lbs. of water in fuel turned into steam and raised in temperature	36,251
		„ radiation and conduction in the 4 hours 12 minutes	70,430
		„ 1,620 lbs. of water raised from 60° and turned into steam at 53 lbs. pressure 1620 × 1.145	1,854,900
			2,468,461
		Unaccounted for	253,979
	2,722,440		2,722,440

The following particulars accompanied the balance-sheet:—

H. M.	Temperature in Flue during Experiment.
1 0 P.M.	670° F.
1 50 „	610
2 55 „	750
4 0 „	770
4 24 „	experiment stopped

The temperature of the air was 70°, the reading of the barometer 30.07 inches.

ANALYSIS OF GAS IN FLUE.

	Before Firing.	After Firing.	Between Firing.	Average.
	per cent.	per cent.	per cent.	per cent.
Carbonic acid	9.42	12.91	10.19	10.84
Oxygen	11.16	7.16	10.16	9.49
Nitrogen	79.42	79.93	79.65	79.67
Combustible gas	—	—	trace	
Total	100.00	100.00	100.00	100.00

Mr. W. Anderson* submitted these results to examination in accordance with Carnot's theory, and succeeded in accounting for a considerable portion of Sir Frederick Bramwell's deficit of 253,979 units of heat "unaccounted for." Mr. Anderson added the "work" required to displace the atmosphere by the waste gases, that is, to produce chimney draught, and by doing so, he remarked that "the unaccounted-for heat falls to less than 4 per cent. of the total heat of combustion. These results show how extremely accurate the observations must have been, and that the loss mainly arises from convection and radiation from the boiler." The result is superior to those announced by Scheurer-Kestner, but probably the use of the anemometer and the method of analysing the waste gases were possible sources of unobserved loss.

The following is Mr. Anderson's analysis :—

"Potential energy of the fuel with respect to absolute zero—

	Units.
238.25 lbs. × 530° abs. × 0.238	= 30,053
194.46 ,, × 17½ × 530° × 0.238 the weight and heat of air	= 420,060
194.46 × 14,544 units heat of combustion of carbon	= 2,828,200
Total energy	3,278,313
Heat absorbed in evaporating 26.08 lbs. of water in fuel	− 29,888
Available energy	3,248,425

"Temperature of furnace—

"The whole of the fuel was heated up, but the heat absorbed in the evaporation of the water lowered the temperature of the furnace, and must be deducted from the heat of combustion.

	Units.
Heat of combustion	2,828,200
,, evaporation of 26.08 lbs. water	− 29,888
Available heat of combustion	2,798,312
Dividing by 238.25 lbs. gives the heat per 1 lb. of fuel used	= 11,745
And temperature of furnace $\frac{11,745}{18.125 \text{ lbs.} \times 0.238} + 530°$	= 3,253°
Temperature of chimney 700° + 460°	= 1,160°

$$\text{Maximum duty } \frac{3,253° - 1,160°}{3,253°} = 0.643$$

"Work of displacing atmosphere by smoke at 700°—

	Cubic Feet.
Volume of gases at 70°	= 228.3
,, ,, 700°	= 499.8
Increase of volume	271.5

* "On the Generation of Steam," &c.: Inst. C.E. Lectures, 1883–84.

	Units.
Work done = $\frac{194.46 \text{ lbs.} \times 271.5 \text{ cub. ft.} \times 144 \text{ sq. in.} \times 15 \text{ lbs.}}{772 \text{ units}}$ =	147,720
Maximum amount of work to be expected = 3,248,425 × 0.643 =	2,101,700
Deduct work of displacing atmosphere . . . . . =	147,720
Available work	1,953,980

"Actual work done—

	Units.
1,620 lbs. of water raised from 60° and turned into steam at 53 lbs. . . . . =	1,855,900
Loss by radiation and convection	70,430
10¼ lbs. ashes left, say at 500°	1,129
Total work actually done . . .	1,927,459
Unaccounted for	26,521
Calculated available work . .	1,953,980

"The work unaccounted for therefore amounts to only 1⅓ per cent. of the calculated available work."

ANALYTICAL TABLES.

FAT BITUMINOUS COALS OF ENGLAND AND SCOTLAND.

Description and Locality of Coal Beds.	By whom analysed and described.	Specific Gravity.	Analysis of 100 Parts of Coal.		
			Carbon.	Bitumen, Volatile Matter, and Water.	Ashes and Cinders.
Alfreton, furnace coal	D. Mushet	1.235	52.46	45.50	2.04
Butterly ,, Derbyshire	,,	1.264	52.88	42.83	4.29
Derbyshire, cannel coal, Alfreton	,,	1.278	48.36	47.00	4.64
Wigan, cannel coal	Dr. Thomson	—	52.60	44.00	3.40
,, ,,	Kerwan	1.272	75.20	21.68	3.10
,, ,,	R. C. T.	1.275	61.73		
Lancashire, ,,	Dunn	—	56.40	41.00	2.60
Woodhall, near Glasgow, cannel coal	Dr. Ure	1.228			
Liverpool coal	Johnson	1.260	54.90	40.48	4.62

FAT BITUMINOUS ADHESIVE COAL, COKED PREVIOUSLY TO USING IN THE FURNACE.

Newcastle-upon-Tyne, Birtley Works	Dufrenoy & Berthier	1.270	60.50	35.50	4.00
,, ,,	Thomson	—	65.90	32.60	1.50
,, ,,	Karsten	1.256	67.65	31.50	0.85
Northumberland, Tyne Works	Dufrenoy & Berthier	—	67.50	30.00	2.50
Staffordshire, Apdale Works	,, ,,	—	62.40	34.10	3.50
Redesale, Newcastle-on-Tyne	Richardson	—	49.95	51.00	3.05
Wylam	,,	—	48.49	37.60	13.91
Garesfield and Auckland	,,	—	72.71	25.90	1.39
Newcastle coal (mean)	W. R. Johnson	1.257	57.00	37.60	5.40

BITUMINOUS COAL, USED CRUDE IN THE HOT-AIR FURNACE.

Description and Locality of Coal Beds.	By whom analysed and described.	Analysis of 100 Parts of Coal.		
		Carbon.	Bitumen, Volatile Matter, and Water.	Ashes and Cinders.
Staffordshire, Tipton, Wednesbury coal works	Berthier	67.50	30.00	2.50
Derbyshire, Butterly, cherry coal	,,	57.00	40.00	3.00
Derbyshire, Codnor Park, soft coal	,,	51.50	45.50	3.00
Soft or mixed English	D. Mushet	53.00		

BITUMINOUS AND SEMI-BITUMINOUS COALS OF SOUTH WALES. ON THE EASTERN SIDE OF THE COAL BASIN.

Description and Locality of Coal Beds.		Thickness of each Bed.	Analysis of 100 Parts of Coal by Mushet. Carbon.	Bitumen, Volatile Matter, &c.	Ashes or Cinders.	The Coal described, and its Uses.
		ft. in.				
Abersychan	Meadow vein	8 6	65.98	29.40	4.62	thin laminæ, furnaces.
	Old coal	2 6	71.10	27.40	2.50	laminæ ,,
Golynos Ironworks	Three-quarter	5 6	71.88	25.50	2.62	,, ,,
	Rock vein	7 0	69.60	27.40	3.00	thin laminæ, run out fires.
	Meadow vein	7 0	68.00	27.50	4.53	dense, furnaces.
	Old coal	2 4	73.40	20.60	6.00	laminæ ,,
Verteg Ironworks. Furnace coal	Red vein	4 0	69.45	26.30	4.25	,, ,,
	Big vein	4 0	66.05	30.70	3.25	irregularly laminated, furnaces.
	Droydeg or rock vein	4 0	64.45	32.30	3.25	oblong, forge and mill.
	Three-quarter	5 6	67.90	29.60	2.50	rather friable, furnace.
	Meadow vein	7 0	69.25	30.50	9.25	thin laminæ ,,
Blaenavon Ironworks	Three-quarter	5 6	65.63	31.25	3.12	,, ,,
	Droydeg or rock vein	5 6	65.55	28.95	5.50	cubical, refineries.
	Meadow vein	2 10	72.00	26.00	2.00	,, furnace.
	Old coal	6 0	75.21	22.29	2.50	laminated ,,
Clydach or Llanelly Ironworks	Red vein	3 0	76.58	20.80	1.62	,, forge and mill.
	Big vein	5 0	73.42	24.58	2.00	thin layers ,,
	Three-quarter	2 9	72.70	25.30	2.00	broad ,,
	Droydeg or rock vein	7 0	72.13	21.87	6.00	cubical ,,
	Tach coal	3 0	70.05	25.57	4.38	cones, household.
	Yard vein	2 9	78.68	19.32	2.00	hard, furnaces.
	Old coal	5 6	77.55	18.95	3.50	alternating laminæ, furnaces.
Nant-y-glo Ironworks	Elled coal	3 6	81.87	17.13	1.00	lamellar ,,
	Three-quarter	—	82.65	15.10	2.25	coking, for the refineries.
	Droydeg vein	—	77.14	17 86	5.00	twisted, forges and mills.
	Old coal	5 6	78.75	18.75	2.50	imperfect, furnaces.
Sirhowey Ironworks	Ell coal	—	82.04	16.71	1.25	sectional ,,
	Three-quarter	—	83.50	12.00	4.30	with numerous partings.
	Big vein	8 0	81.52	15.10	3.38	rhomboidal, furnace.
	Mudelog vein or droydeg	—	80.50	11.87	7.63	partially granulated.
	Yard coal	—	82.24	15.88	1.88	twisted, with clod.
	Engine coal	4 0	82.46	15.41	2.13	irregularly granular, furnaces.
	Three-quarter engine	—	75.78	13.22	11.00	hard.
	Old coal	4 0	78.50	13.00	8.50	conchoidal partings.
Ebbw Vale Ironworks	Yard coal	3 2	81.04	15.83	3.13	friable, forges and mills.
	Three-quarter	3 0	80.25	17.00	2.75	cubical, blast furnaces.
	Big vein	4 8	81.37	17.00	1.63	,, ,, and forges.
	Bydelog or droydeg	2 10	72.88	16.87	10.25	coarse ,, ,,
	Ell coal	3 2	82.32	16.30	1.38	granular ,, ,,
	Old coal, top	5 6	79.28	18.22	2.50	cubical, force and mill.
	,, bottom		81.77	15.73	2.50	less granular, blast furnace.
Beaufort	Old coal	4 6	76.82	20.80	2.38	cubical, furnace and refinery.
Pont-y-mister	Forge coal	—	75.06	22.22	2.72	,, ,, forge.
Blaina	Big vein	5 6	72.14	25.86	2.00	granular ,, ,,
	Three-quarter	5 6	77.38	21.12	1.50	cubical ,, ,,
Tredegar Ironworks	Big vein, top	3 0	80.45	16.55	3.00	compact, blast furnace.
	,, lower part	3 0	81.56	14.94	3.50	very compact ,,
	Red vein, upper part	1 0	79.44	14.06	6.50	laminated.
	,, under part	3 0	80.26	18.49	1.25	reedy laminæ, blast furnace.
	Bydelog (droydeg)	3 0	78.90	17.97	3.13	fine laminæ, forge.
	Yard vein	—	82.26	15.36	2.38	reedy laminæ, blast furnace.

BITUMINOUS AND SEMI-BITUMINOUS COALS OF SOUTH WALES—(*continued*).

Description and Locality of Coal Beds.		Thickness of each Bed.	Analysis of 100 Parts of Coal by Mushet. Carbon.	Bitumen, Volatile Matter, &c.	Ashes or Cinders.	The Coal described, and its Uses.
		ft. in.				
Tredegar Ironworks	Penmark vein	—	80.11	14.06	5.83	reedy, forges and mills.
	Three-quarter	—	80.20	13.80	6.00	laminæ with clod.
	Engine coal, or old coal	5 6	77.30	15.20	7.50	reedy.
Rhymney Ironworks	Big vein, upper part	—	81.26	16.24	2.50	partially reedy, blast furnace.
	,, lower part	—	82.33	13.17	4.50	strong ,,
	Raslas vein	7 0	82.79	12.96	4.25	reedy ,,
	Brassey vein	1 3	83.38	14.37	2.25	twisted, workmen's fires.
	Red coal	3 6	84.25	12.75	3.00	granular, furnaces.
	Yard coal	—	80.92	16.20	2.88	irregular ,,
	Four-feet coal	—	80.15	15.10	4.75	irreg. laminæ, forges and mills.
	Fire-clay coal	1 0	80.60	17.40	2.00	reedy.
	Black vein	2 6	82.51	14.99	3.50	,, forge.

SEMI-BITUMINOUS OR STEAM COALS OF SOUTH WALES.

Bute Ironworks	Red vein	4 0	83.04	14.58	2.38	thin laminæ.
	Big vein	9 0	83.53	13.74	2.73	,,
	Raslas vein	9 0	84.06	12.44	3.50	,,
	Four-feet vein	4 0	78.30	16.45	3.25	in compact, forges.
Dowlais Ironworks	Big vein, upper part	11 0	80.88	15.62	3.50	reedy, blast furnaces.
	Middle part		85.00	11.87	3.13	thin layers, brittle.
	Bottom part		82.81	13.44	3.75	irregular, shining.
	Raslas vein, upper part	9 0	84.08	13.02	2.90	imperfect, cleavage.
	Lower part		85.02	13.23	1.75	strong, laminæ thin.
	Upper four-feet	4 0	85.75	12.75	1.50	prisms, furnace coal.
	Lower four-feet	4 0	85.35	12.40	2.25	shining laminæ.
	Cwmcenol	2 9	88.63	9.74	1.63	in layers, furnace coal.
	Four-feet forge	5 0	88.78	7.97	3.25	part reedy, forge coal.
	Little vein	3 0	86.90	11.72	1.38	thin laminæ, forges.
*Pen-y-darren Ironworks	Foes-y-frane	7 0	85.04	11.46	3.50	compact, blast furnaces.
	Raslas	7 0	87.69	10.31	2.00	incompact ,,
	Three-feet coal	3 0	85.07	12.18	2.75	broad ,,
	Four-feet coal	4 0	88.50	10.00	1.50	hard ,,
	Upper vein	3 6	86.08	10.42	3.50	,, forges and mills.
	Roof-pin vein	2 0	83.30	11.20	5.50	,, mixed quality.
	Big vein	—	86.01	12.24	1.75	crystallized, with clod.
	Bottom coal	4 0	87.20	11.30	1.50	compact, forges.
*Plymouth & Duffryn Ironworks	Upper or yard coal	3 9	79.06	15.34	5.60	mixed ,,
	Four-feet coal	4 0	84.98	11.77	3.25	,, less shining.
	Clynmil coal, top part	3 6	86.62	12.00	1.38	conical, best furnace coal.
	Bottom part	4 6	85.48	12.39	2.13	granular, blast furnaces.
	Raslas, top part	4 6	82.05	13.95	4.00	bright ,,
	Bottom part	3 6	83.84	13.33	2.83	both reedy and granular.
	Upper Dingle coal	3 6	77.00	20.00	3.00	broad, forges and mills.
	Lower Dingle	2 6	80.34	16.66	3.00	less bright and shining.
*Cyfarthfa & Ynnis Vach. Merthyr Ironworks	Cyfarthfa big vein	9 0	90.28	7.97	1.75	slightly reedy.
	Cwm-dhu pit	6 0	88.78	9.22	2.00	regularly laminated.
	Cwm-mynedd	5 6	88.87	9.00	2.13	slaty, forges and mills.
	Cwm-y-glo	4 0	89.29	6.58	4.13	incompact, blast furnaces.
	Upper yard vein	3 0	86.80	11.20	2.00	regular ,,
	Gelly-deg	3 0	91.86	6.14	2.00	specular, forges.
	Mountain vein	3 6	90.02	8.48	1.50	crystallized, furnaces.
	,, ironstone	1 6	92.11	6.14	1.75	reedy, granular.

* On the northern side of the coal basin.

SEMI-BITUMINOUS OR STEAM COALS OF SOUTH WALES—(*continued*).

Description and Locality of Coal Beds.		Thickness of each Bed.		Analysis of 100 Parts of Coal by Mushet. Carbon.	Bitumen, Volatile Matter, &c.	Ashes or Cinders.	The Coal described, and its Uses.
		ft.	in.				
Aberdare Ironworks	Four-feet coal	4	0	87.00	11.50	1.50	compact, blast furnaces.
	Raslas vein	10	0	88.89	9.11	2.00	„ forges.
	Two-feet coal	2	0	88.12	10.00	1.88	mixed reedy and granular.
	Small vein	5	6	80.42	10.83	8.75	compact, refineries.
	Foes-y-frane	4	0	84.67	8.33	7.00	„ furnaces.
	Two-feet 9-inch coal	2	9	88.51	9.99	1.50	bright reedy coal.
	Yard vein	—		82.99	14.26	2.75	reedy, furnaces.
	Black mine coal	—		91.18	6.82	2.00	bright reeded coal.
	Upper vein	—		82.12	12.13	5.75	granular, with clod.
Hirwain Ironworks	Big vein	9	0	88.94	7.18	3.88	crystallized, forges.
	Four-ft. coal, or Glowynn	4	0	90.26	7.86	1.88	slightly reedy, furnaces.
	Six-feet coal	6	0	82.96	8.04	2.06	regular reeded, forges.
	Pit vein	3	0	87.15	8.85	4.00	reedy and granular.
*Argoed in Cwm Buchan	Upper vein	3	0	76.54	22.50	0.96	friable, weak.
	Lower vein	3	0	74.30	23.40	2.30	harder, more compact.
*Oakwood Glamorgnsh. second coal series	Wern Dhu	2	3	78.02	20.18	1.80	used for smelting iron.
	Wern Pistill	2	6	80.06	17.46	2.48	hard, compact.
	Rider vein	—		80.67	18.52	0.81	second coal series.
	Tor Mynydd	1	8	81.18	18.00	0.82	„ „
*Cwm Buchan third coal series	Four-feet, upper vein	4	0	91.67	7.70	0.63	strong, heavy coal.
	„ lower part	4	0	88.65	10.00	1.35	reedy, furnaces.
	Nine-feet coal	9	0	83.74	15.20	1.06	large and lumpy.
	Yard coal	—		78.90	20.00	1.10	clean and bright.
*Pyle, lower series	Vein fawr, 1	9	0	72.82	24.68	2.50	very bright reedy coal.
	„ 2	9	0	72.58	24.42	3.00	cannel and bituminous mixed.

BITUMINOUS AND SEMI-BITUMINOUS OR STEAM COALS OF SOUTH WALES, ON THE SOUTH-EASTERN SIDE OF THE COAL BASIN.

Mynyddy-swyn vein, sale coals for household purposes, Upper or red ash coals	Cyfarthfa furnace	—		88.07	8.50	3.43	irregular crystallized.
	Powell's	4	0	66.58	27.92	5.50	cubical, compact, reedy.
	Morrison's	4	0	68.58	36.92	4.50	„ „ „
	Penner vein	4	0	60.25	33.00	6.75	slightly granular, reedy.
	Cwm Dows (Morrison)	3	4	68.86	27.14	4.00	cubical.
	Prothero's	4	0	64.95	33.30	1.75	„ compact.
	Rosser Williams	4	0	68.50	30.00	1.50	no sulphur, clean.
	Crossfield's	—		69.34	24.16	6.50	cubical, compact.
Beddws vein, Lower red ash coal	Cwm Tillery	2	4	64.45	24.80	10.75	shining bright.
	Phelps's	2	4	68.00	30.00	2.00	compact, hard, strong.
	Abercarne	2	9	66.88	28.37	4.75	„ cubical, reedy.
	Cwm Carne	2	9	62.63	31.10	6.25	„ „ „
† Risca veins	Upper rock vein	3	6	66.11	31.14	2.75	for steam-packets.
	Lower rock vein	3	6	61.78	34.28	3.94	oblong masses, reedy.
	Big vein	12	0	66.02	29.15	2.83	irregular, no sulphur.
	Red vein	—		61.25	33.80	4.95	pyrites, strong.
	Sun vein or Meadow vein	3	0	67.28	31.34	1.38	compact, reedy.
† Cwm Brane coals	Yard vein	2	0	63.03	32.60	4.37	with layers of splint.
	Rock vein	6	0	62.22	34.78	3.00	cubical.
	Red vein	3	6	60.65	31.35	8.00	oblong, reedy.
	Meadow vein	5	8	66.34	28.16	5.50	strong, bright, shining.
	Old coal	3	0	68.30	27.70	4.00	cubical, tarnished.

* South side of the coal basin.

† The white ash or furnace coals.

STEAM COALS OF SOUTH WALES—(*continued*).

Description and Locality of Coal Beds.		Thickness of each Bed.	Analysis of 100 Parts of Coal by Mushet. Carbon.	Bitumen, Volatile Matter, &c.	Ashes or Cinders.	The Coal described and its Uses.
		ft. in.				
* Blaen-dare furnace coals	Rock vein	10 0	68.86	28.64	2.50	used for blast furnaces.
	Meadow vein	6 0	67.84	29.16	3.00	,, ,,
* Pen Twyn furnace coals	Big vein	4 6	71 88	25.50	2.62	laminæ regular, reedy.
	Droydeg, or rock vein	3 6	68.20	24.80	7.00	cubical.
	Meadow vein	7 0	63.65	32 60	3.75	cross or sectional, pure.
	Old coal	2 6	68.50	27.50	4.00	incompact, friable.
Abersychan British Iron Company	Red vein	4 0	72.95	25.30	1.75	used raw in blast furnaces.
	Big vein	7 0	67 05	25.70	7.25	,, ,,
	Rock vein	8 0	69.30	25.70	5.00	cubical, splint.
† Park, south veins of the South Wales coal basin, between Pyle and Llantrissant	Cribbwr Vach	4 6	72.36	26.14	1.50	bright, furnaces.
	Bedws vein	10 0	70.68	25.82	3.50	,, in thin laminæ.
	Maesteg issa	5 0	79.69	19.26	1.25	,, blast furnaces.
	Llangonydd	5 0	60.40	38.60	1.00	,, ,,
	,, No. 2	2 6	69.64	27.86	2.50	imperfectly rhomboidal.
	,, 20-inch	1 8	70.22	28.28	1.50	broad, reedy coal.
	Hirwain common	4 6	69.34	29.16	1.50	smooth fracture.
	,, 2-yard coal	4 0	73.75	22.50	3.75	slaty, partially reedy.
	Llanharry	6 0	65.75	33.00	1.25	strong, reedy coal.
	Collenna 3-feet	3 0	75.06	23.44	1.50	broad, reedy structure.
	,, cannel coal	3 0	63.25	34.12	2.63	laminated, oolitic.
† Mellin Criffin and Pentyrch, near Cardiff	Little vein	—	70.66	27.34	2.00	workmen's fires.
	Brassey vein	2 4	61.00	30.00	9.00	heavy, forges and mills.
	Pentyrch hard vein	4 0	71.25	23.75	5.00	crystallized, blast furnaces.
	,, forked vein	5 6	64.63	31.87	4.50	reedy, tin plate works.
	,, wing coal					
	Pure anthracite	5 0	95.69	2.81	1.50	,, furnace and forge.
Very dry, with excess of carbon in S. Wales	Dowlais ironworks	—	79.50	17.50	3.00	lamellar, does not cake.
	Cyfarthfa ,,	—	78.40	18.80	2.80	,, cakes.
	Pen-y-darran ,,	—	76.80	20.00	3.20	,, ,,

ANTHRACITE OF SOUTH WALES, TOWARDS THE WESTERN EXTENSION OF THE BASIN.

Pwll-feron, in Neath valley, Neath Abbey furnaces	Pwll-feron vein, 1st bed	18 0	89.34	6.66	4.00	mixed with coke.
	,, ,, 2nd ,,		86.56	6.94	6.50	very hard and reedy.
	,, ,, 3rd ,,		86.24	12.00	1.76	anthracite.
	,, ,, 4th ,,		90.59	8.50	0.91	,,
	,, ,, 5th ,,		91.08	8.00	0.92	more brilliant.
	,, ,, 6th ,,		81.00	9.00	10.00	more reedy.
Yniscydwn Ironworks	Big vein	—	88.70	7.80	3.50	
	Brass vein	—	88.70	7.80	3.50	
	Cwm Phil vein	—	89.60	6.66	3.74	bright and shining.
Swansea	Swansea peacock coal	—	89.00	7.50	3.50	surface smooth.

* The white ash or furnace coals.

† Bituminous coals of South Wales, south side of the canal basin.

By the term "reedy coal" is locally understood a coal in which the vegetable impressions are conspicuous and abundant in its substance,—"Clod coal," having a soft, laminated vegetable texture,—"Splint coal," which does not lose its form in coking, angular,—"Semi-bituminous coal coke," where the angles of the cokes are rounded, and having considerable adhesion,—"Partially bituminous," where the coked masses have rounded edges, and slightly adhere together,—"Bituminous cokes," those which dissolve and enter into fusion, forming a compact mass.

ANTHRACITE OF SOUTH WALES—(*continued*).

Description and Locality of Coal Beds.		Thickness of each Bed.	Analysis of 100 Parts of Coal by Mushet.			The Coal described, and its Uses.
			Carbon.	Bitumen, Volatile Matter, &c.	Ashes or Cinders.	
		ft. in.				
Ystal-y-fera Ironworks, Swansea valley	Big vein, 1st bed	6 0	91.42	7.08	1.50	blast furnaces.
	" 2nd "		92.89	5.61	1.50	flat, boarded coal.
	" 3rd "		91.99	6.51	1.50	reedy and granular.
	Cefn vein, upper bed	—	91.26	7.24	1.50	pitchy, bright, shining.
	" lower part	—	91.89	6.61	1.50	partially granular.
	Brass vein, upper part	—	92.46	6.04	1.50	bright, laminæ irregular.
	" lower "	—	91.52	6.98	1.50	irregular, reedy.
	Black vein	—	93 14	5.36	1.50	rough, crystallized.
	Little vein	—	90.64	7.86	1.50	regular, but twisted.
	Pentyrch wynn	5 0	95.69	2.81	1.50	reedy, forge and furnace.
Cwm Neath	Three-feet vein	3 0	94.10	4.90	0.93	analysis by D. Schafhaeutl.
	Eighteen-feet vein	18 0	91.43	6.24	2.28	
	Nine-feet vein	9 0	93 12	5.22	1.59	
Bituminous coals of the Forest of Dean, Gloucestershire	Cinderford furnace, or Lower High coal Delf	3 0	62.00	36.00	2.00	strongly reeded, bright.
	Park-end coal	4 0	—	—	—	free from splint.
	Coleford High Delf, top part	4 6 to 6 0	63.72	32.03	4.25	thin, bright laminæ.
	Middle part		63.61	34 89	1.50	reedy, bright, pyritous.
	Bottom "		60.96	37.29	1.75	smooth fracture.
	Churchway coal (top)	5 0	60.33	35.67	4.00	irregular fracture.
	Churchway coal (bottom)		64.13	34.74	1.23	smooth, straight, reedy.
	Rocky vein	2 0	61.73	36.14	2.13	strong, partially reedy.
	Starkey coal	2 6	61.53	36.72	1.75	partially reedy.
	Park-end, Little Delf	1 8	58.15	36.35	5.50	compact, bright, reedy.
	" Smith End	2 0	63.36	34.89	1.75	heavy, compact, reedy.
*Corbyn's Hall	Tow coal, part of the ten-yard coal	—	51.90	40.60	7.50	strong, reedy coal.
	" "	—	56.00	42 50	1.50	irregularly laminated.
	Heathing coal	—	54.17	43.33	2.50	strong, bright, reedy.
	Brooch coal	—	50.49	47.76	1.75	bright, pitchy fracture.
*South Staffordshire	New mine top coal	—	52.77	45.10	2 13	reedy, without splint.
	Fire-clay coal	—	51.40	46.35	2.25	weak, friable, reedy.
	New mine bottom coal	—	53.98	44.27	1.75	reedy, mixed with clod.
*Bentley Estate, South Staffordshire	Ten-yard coal	—	54.05	42.70	3.25	pitchy, bright coal.
	" bottom part	—	63.57	34.18	2.25	bright and thin splint.
	Four-feet coal	4 0	53.18	44.82	2.00	bright, shining, smooth.
	Three-feet coal	3 0	54.82	43 12	2.00	bright, pitchy, reedy.
	Fire-clay coal	5 0	54.84	42.91	2.25	strong, reedy, uniform.
	Bottom vein	7 0	62.87	32.00	5.12	hard, splint coal.
	Five-feet splint coal	5 0	49.42	45.83	4.75	laminæ minute.
	Bottom coal	—	79.78	10 72	9.50	imperfectly crystallized.
Land end, North Staffordshire	Bassey mine coal	—	58.30	38.70	3.00	reedy, dull surfaced.
	Little mine coal	4 0	62.30	35 20	2.50	compact.
	Great row coal	9 0	57.38	39.74	2.88	smooth, thin laminæ.
	Best furnace coal	10 0	65.20	32.30	2.50	bituminous-looking coal.
	Ashes coal	—	61.32	37.18	1.50	bright, shining, cubical.

* Bituminous coals of Staffordshire.

BITUMINOUS COALS OF STAFFORDSHIRE, SHROPSHIRE, NORTH WALES, DERBYSHIRE, AND YORKSHIRE.

	Description and Locality of Coal Beds.	Thickness of each Bed.	Analysis of 100 Parts of Coal by Mushet. Carbon.	Bitumen, Volatile Matter, &c.	Ashes or Cinders.	The Coal described, and its Uses.
		ft. in.				
North Staffordshire Kidsgrove	Little Row coal	4 0	63.08	34.67	2.25	bright, with clod partings.
	Seven-feet coal	7 0	67.90	30.47	1.63	thin layers, furnace.
	Stony vein	8 0	65.17	33.33	1.50	compact.
	Banbury or Harecas	—	63.84	35.16	1.00	bituminous.
Golden H.	Knowles's coal, Delph Lane	10 0	59.64	37.86	2.50	bright, free burning.
	Peacock coal, Fenton Park	9 0	60 42	37.08	2.50	cubical, furnaces.
	Spendcroft vein	4 0	58.67	39.58	1.75	broad, potteries.
	Ten-feet coal	7 0	58.89	39.11	2.00	uniformly reedy, potteries.
	Great Row coal	8 0	60.80	37.70	1.75	cubical, potteries and salt works.
	Little Row coal	4 0	62.47	34.53	3.00	hard " "
Shropshire	Shropshire stone coal	—	58.17	39.20	2 63	bright, clod partings.
	Sulphur coal	—	55.72	42.03	2.25	broad, for inferior house purposes.
	Clod coal	—	63.79	35.58	1.63	reedy, furnaces.
	Randle coal	—	61.19	32.81	3.00	" "
	Flint coal	—	60.63	36.87	2.50	hard, sale or smith's use.
	Top coal	—	64.10	34.77	1.13	regular.
	Best fungous coal	—	63.33	35.67	1.00	minutely laminated, no pyrites.
	Double coal	—	57.87	41.38	0.75	hard, blast furnace.
North Wales Brymbo Coals	Three-yard coal, part not coked	—	61.31	35.80	2.89	fine "
	" part coked	3 0	62.70	35.70	1.60	strong "
	Two-yard coal coked	—	69.98	28.60	1.42	bright "
	Brassey vein coked	5 6	64.58	34.10	1.32	cubic "
	Crank coal	2 6	73.56	25.70	0.74	mixed, furnace and sale.
	Drowsall vein	5 0	62.69	36.70	0.60	not firm, free.
	Powell vein	5 0	63.41	34.80	1.79	shining.
Dee Bank	Five-yard vein, top part	—	61.89	36.20	1.91	laminated, free.
	" middle	—	62.72	36.00	1.28	more compact, iron-making.
	" bottom	—	63.79	32.85	3.36	thin laminæ, with clod.
	Three-yard coal	—	62.88	36.00	1.12	compact, free.
	Two-yard coal	—	60.61	38.47	0.92	free, shining fracture.
	Bone coal	—	55.20	40.00	4.80	hard, lead works.
North Wales	Pankey Ironworks, stone vein	2 0	61.95	35.67	2.38	broad, partly crystallized.
	Pant Ironworks, blast furnace coal	1 7	67.25	31.25	1.50	granular, for blast furnace.
	Coed Talon	9 0	58.50	40.00	1.50	surface "
	Sweeny colliery, Brassey vein	3 0	49.94	34.56	15.50	alternate layers "
	Cefn colliery, near Ruabon works	7 0	57.49	36.56	6.25	"
	" Brassey coal	3 0	66.37	32.13	1.60	laminated.
	Black Park coal, 2-yard vein	6 0	57.50	40.00	2.50	firm, with splint.
	" 1¼-yard vein	4 6	59.88	38.12	2.00	strong, with clod.
	Llwyn-y-onnion, ½-yard coal	—	62.85	34.40	2.75	smooth, reedy, blast furnace.
	Chirke bank colliery, strangers coal	5 6	57.00	40.00	3.00	hard.
	Delf colliery, yard vein, near Ruabon	—	64.89	34.11	1.00	compact.
Derbyshire	Kirby, upper hard or main coal	6 0	64.15	33.85	2.00	mixed, shining parting.
	Dunshill, near Swanwick	—	55.77	40.73	3.50	strong, breaking oblong.
	Swanwick, main coal	—	60.27	38.23	1.50	" twisted laminæ.
	Main, upper hard, Duckmanton	—	64.47	32.03	3.50	" blast furnaces.
	Normanton Com. Codnor Park	—	56.21	41.66	2.13	free, forge and mills.
	Main soft coal	—	56.49	37.76	5.75	" clod, spar.
	Alfreton works, lower hard coal	4 0	62.60	35.15	2.25	strong, blast furnaces.

BITUMINOUS COALS OF STAFFORDSHIRE, ETC.—(*continued*).

	Description and Locality of Coal Beds.	Thickness of each Bed.	Analysis of 100 Parts of Coal by Mushet. Carbon.	Bitumen, Volatile Matter, &c.	Ashes or Cinders.	The Coal described, and its Uses.
		ft. in.				
Derbyshire	Butterly Park coll., lower hard coal	—	61.14	34.11	4.75	splint, blast furnaces.
	Moreley Park works „	—	55.89	37.86	6.25	„ „
	Chesterfield „	—	61.65	35.10	3.25	mixed, good cleavage.
	Double or Minge coal . .	—	60.66	37.34	2.00	bright, furnaces.
	Clod coal	—	61.21	37.29	1.50	smooth fracture.
	Buckland Hollow or Kilburn coal	—	58.62	40.00	1.38	broad, smooth fracture.
	Moreley Park, cannel coal .	—	45.00	45.05	9.95	conchoidal.
	Cannel coal near Alfreton works	—	55.27	40.73	4.00	beautiful, specular.
Yorkshire	Low Moor, better bed . .	2 4	67.06	32.19	0.75	dense, furnace and forge.
	„ black bed . .	1 8	71.42	27.08	1.50	friable, domestic use.
	Bowling, better bed . . .	1 10	64.25	32.55	2.00	bituminous, furnace and forge.
	„ crow coal . . .	1 8	66.15	33.85	1.00	distinct, with clod, sale.
	Parkgate, main coal . .	7 0	67.14	30.73	2.13	four-feet, blast furnaces.
	Old Parkgate vein . . .	4 6	65.09	33.28	1.63	hard, in laminæ „

FAT BITUMINOUS COALS OF YORKSHIRE AND SCOTLAND.

Description and Locality of Coal Beds.	By whom analysed and described.	Thickness of each Bed.	Analysis of 100 Parts of Coal. Carbon.	Bitumen, Volatile Matter, Water, &c.	Ashes or Cinders.
YORKSHIRE.		ft. in.			
Parkgate, top coal, upper part of the 7-ft. cl.	D. Mushet . . .	1 4	62.51	36.49	1.00
„ bottom part	„ . . .	1 8	66.94	31.56	1.50
Birkenshaw coal	„ . . .	—	64.96	32.54	2.50
Worsboro' furnace coal	„ . . .	9 0	60.32	38.18	1.50
„ another specimen . . .	„ . . .		56.45	40.85	2.50
Milton, main coal, splint part . .	„ . . .	9 0	69.40	27.60	3.00
„ roof or soft part. . . .	„ . . .		62.71	36.04	1 25
Thorncliffe, thin furnace coal. . .	„ . . .	2 6	63.98	35.52	0.50
Smithy, wood coal.	„ . . .	2 6	54.60	44.27	1.13
Easley Park	„ . . .	1 7	69.12	30.00	0.88
Yorkshire Kent coal	„ . . .	5 0	66.40	32.72	0.88
Stafford, main coal, 5-feet, bottom part .	„ . . .	3 0	62.08	35.67	2.25
„ „ „ top part .	„ . . .	2 0	68.12	30.20	1.68
Silkstone, main coal	„ . . .	—	65.08	32.29	2.63
„ soft or clod coal . . .	„ . . .	5 0	63.10	35.15	1.75
SCOTLAND.					
Clyde, upper vein, top	„ . . .	—	37.00	41.50	21.50
„ „ bottom . . .	„ . . .	—	53.45	44.80	1.75
„ second vein	„ . . .	—	42.10	48.34	9.56
„ third or furnace . . .	„ . . .	—	51.20	45.50	3.30
„ fifth splint coal . . .	„ . . .	—	53.40	42.40	4.20
Calder, furnace coal, top . . .	„ . . .	—	49.98	43.82	6.20
„ „ splint part . .	„ . . .	—	50.67	47.48	1.85
„ „ main coal, top . .	„ . . .	—	49.60	49.39	1.01

FAT BITUMINOUS COALS OF YORKSHIRE AND SCOTLAND—(*continued*).

Description and Locality of Coal Beds.	By whom analysed and described.	Thickness of each Bed.	Analysis of 100 Parts of Coal.		
			Carbon.	Bitumen, Volatile Matter, Water, &c.	Ashes or Cinders.
SCOTLAND—(*continued*).		ft. in.			
Calder, furnace coal, middle	D. Mushet	—	52.30	39.95	7.75
,, ,, bottom	,,	—	51.60	44.51	3.89
Glen Buck, furnace coal	,,	—	53.20	45.20	1.60
,, inferior coal	,,	—	48.80	44.20	7.00
Cleugh, furnace coal	,,	—	47.08	42.25	10.67
Omoa, splint ,,	,,	—	—	46.62	
,, bright ,,	,,	—	—	47.29	
Marystone, Pyotshaw coal, top	,,	—	49.60	49.31	1.09
,, pine splint	,,	—	51.82	46.57	1.61
,, heavy splint	,,	—	54.67	39.25	6.08
Fat bituminous Coals.					
Govan coal, first vein, top part	,,	—	49.55	44.65	5.80
,, ,, lower part	,,	—	49.41	48.92	1.67
,, second vein	,,	—	42.20	48.34	9.46
,, fifth vein, splint	,,	—	48.84	49.79	1.37
,, sixth vein, lower main—					
1. Craw coal	,,	—	51.58	44.60	3.82
2. Head coal	,,	—	48.08	49.38	2.54
3. Ground coal	,,	—	44.57	51.00	3.43
4. Foot coal	,,	—	52.27	44.15	3.58
Lesmahagow, cannel coal	,,	—	39.43	56.57	4.00
Dry Coals, not very adhesive.					
Clyde, splint coal	,,	—	59.00	36.80	4.20
,, ,,	Thomson	—	55.23	35.27	9.50
,, clod coal	D. Mushet	—	70.00	26.50	4.50
,, soft coal	Thomson	—	42.25	47.75	10.00
,, near Glasgow	Dufrenoy and Berthier	—	64.40	31.00	4.60
Calder ,,	,,	—	51.00	45.00	4.00
Monkland ,,	,,	—	56.20	42.40	1.40
Middlerig	Dr. Fyfe	—	50.50	42.00	7.50
Scotch coal	W. R. Johnson	—	48.81	41.85	9.34
,, cannel	,,	—	60.34	36.95	2.71
,, ,,	Dr. Ure	—	39.40	56.60	4.00

Locality or Name of Coal.	Analyst.	Specific Gravity.	Volatile Matters. Per Cent.	Fixed Carbon. Per Cent.	Ash. Per Cent.	Sulphur. Per Cent	Water. Per Cent.	Coke. Per Cent.
Rochsoles cannel	Dr. Penny	1.448	53.7	4.9	38.8	1.60	1.0	43.70
Hardie's ,,	,,	1.420	34.0	4.0	58.4	—	3.6	64.40
Boghead, brown cannel	,,	1.160	71.0	7.1	21.2	0.24	0.4	28.30
,, black ,,	,,	1.218	62.7	9.2	26.5	0.35	1.2	35.75
Torbanehill cannel	,,	1.189	67.1	10.5	21.0	0.32	1.0	31.52
Boghead ,,	,,	1.155	71.3	11.3	16.8	(0.34)	0.6	28.10
Bathville ,,	,,	1.201	64.3	12.6	22.2	0.25	0.6	34.80
Stand, Airdrie, cannel	,,	1.464	52.0	14.7	32.0	—	1.1	46.77
Methill	,,	1.300	49.2	17.5	29.7	—	3.5	47.27
Capeldrae	,,	1.360	45.7	19.9	31.5	—	2.8	51.47
Wemyss	,,	1.183	58.5	25.2	14.2	—	1.9	39.53
Balbardie	,,	1.420	38.9	29.6	28.0	0.38	3.0	57.66
Hillhead, Kilmarnock, cannel	,,	1.602 1.320	36.6	32.3	27.4	0.61	3.0	59.74
Brymbo	,,	—	32.1	36.4	29.4	—	2.1	65.80
Lesmahagow, Auchinheath	,,	1.199	56.2	36.7	4.3	0.55	2.2	41.00

Locality or Name of Coal.	Analyst.	Specific Gravity.	Volatile Matters. Per Cent.	Fixed Carbon. Per Cent.	Ash. Per Cent.	Sulphur. Per Cent.	Water. Per Cent.	Coke. Per Cent.
Bartonshill	Dr. Penny	1.280	40.0	39.6	10.0	2.00	2.4	49.60
"	"	1.350	38.0	37.9	18.7	2.20	3.2	56.60
Stevenston, Ayrshire	"	1.385	40.2	40.1	19.3	—	0.3	59.49
Lesmahagow, Southfield	"	1.228	49.3	40.9	6.3	1.35	2.0	47.31
Knightswood	"	1.234	44.7	41.1	11.0	—	3.0	52.18
Cambroe	"	1.247	42.8	42.6	8.5	—	6.0	51.17
Skaterigg	"	1.252	49.3	44.8	2.5	—	3.3	47.33
Cowdenhill	"	1.299	46.0	45.0	5.0	0.50	3.5	50.00
Bredisholme	"	1.335	39.0	48.5	8.1	0.40	4.0	56.60
Ruchill	"	1.223	45.7	49.2	2.5	—	2.5	51.77
Kelvinside	"	1.213	40.1	53.4	1.9	0.21	4.3	55.32

ANTHRACITES OF EUROPE.

Localities.	By whom examined and analysed.	Specific Gravity.	Analysis of 100 Parts		
			Carbon.	Hydrogen, Water, and Volatile Matter.	Silica and Ashes.
South Wales.					
Anthracites.					
Welsh anthracite, Cwm Neath	Dr. Schafhaeutl	—	92.42	5.97	1.91
			94.10	4.90	0.93
Ynis Cedwin, Crane	Jno. F. Frazer	—	86.60	7.60	5.80
"	W. R. Johnson	1.336	87.60	9.18	4.32
		1.372			
Welsh stone coal	D. Mushet	1.368	89.70	8.00	2.30
Welsh slaty stone coal	"	1.409	84.17	9.10	6.73
Mean of several varieties of Welsh coal	Dr. Fyfe's experiment	1.354	71.40	17.80	10.80
European Continent.					
Anthracitous Coals.					
The Alps, Isère, Canton of Lannure	M. Robin	—	—	—	0 40
Canton of Lanton, near Grenoble	"	1.072	—	—	—
Westphalia	M. Karsten	1.358	—	—	—
"	"	1.336	—	—	—
Mean analysis of twelve varieties of anthracite	Berthier	—	79.15	7.37	13.25
Dry or Slightly Bituminous Coals.					
Ireland.					
Kilkenny, Leinster	D. Mushet	1.602	92.88	4.25	2.87
" slaty or cannel	"	1.445	80.47	13.00	6.53
Boolavoonein, stone coal	"	1.436	82.96	13.80	3.24
Corgee "	"	1.403	87.49	9.10	3.40
Queen's county, Leinster	"	1.403	86.56	10.30	3.14
Kilkenny, cannel	Karsten	—	74.47	25.01	0.50
"	Dr. C. T. Jackson	—	79.60	12.00	8.40
Scotland.					
Coal, under basalt, Renfrewshire	D. Mushet	—	69.74	16.66	13.60
Dalmellington, Ayrshire	Dr. Penny	1.453	87.70	8.70	3.60
France.					
Mean of twelve specimens	M. Berthier	—	79.15	7.37	13.25
Côte-d'Or, Sincey	De Nerville	—	82.60	8.60	8.80
Mais Salze	M. Varin	—	83.00	7.50	9.50

BITUMINOUS COALS OF FRANCE.

Departments, Coal Basins, and Varieties of Coal.	Locality.	Concessions.	By whom analysed.	Specific Gravity.	Analysis.		
					Carbon.	Volatile Matter.	Ashes.
*Basin of Fins	Montet		M. Baudin	1.38	75.23	24.77	
	Gabeliers		„	1.34	74.92	25.08	
	Deux Chaises, Chapelle		„	1.48	74.22	25.78	
	Fins		„	—	68.28	31.72	
	Noyant		„	1.30	62.49	37.51	
*Basin of Bussière-la-grue			„	1.34	54.76	45.24	
*Basin of Bert			„	1.36	58.47 64.20	41.53 35.80	
*Basin of Commentry	Commentry		M. Regnault	—	63.20	36.60	1.20
	Chambled	Marais	„	1.38	87.85	12.15	
	Commentry	Amenat	„	1.27	60.00	40.00	
	Néris	Great bed	„	1.35	58.87	41.13	
	„	Ferrières	„	1.31	56.76	43.24	
*Basin of Doyet	Doyet	La Souche	„	1.30	61.23	38.77	
	Monticq	Bourdignat	„	1.28	59.58	40.42	
	„	Chauvais	„	1.30	58.61	41.39	
	Bezenet	Grand masse	„	1.32	56.84	43.16	
Champagnac in the coal basin of Haute-Dordogne—Cantal	Mines de Lempret	New bed 1	M. Baudin	1.26	66.60	30.19	4.60
		2 metres 2	„	1.33	56.30	29.80	13.90
		3	„	1.36	53.20	30.30	16.50
		Upper bed 4	„	1.28	65.70	30.10	4.20
		5	„	1.27	62.40	30.60	7.00
	Mine de Madie	First or lowest bed 6	„	1.28	60.70	32.90	6.40
		2nd bed 7	„	1.28	64.00	31.60	4.40
	Mauriac	Madie	M. Berthier	—	61.00	34.50	7.50
Coal Basin of Haute-Dordogne—Cantal	1. Messeix	Clydance	„	1.39	85.49	14.51	
	2. Singles	Morilleux	„	1.38	71.27	28.73	
	3. Lempret	New bed	„	1.38	69.10	30.90	
	4. Madie	2nd bed	„	1.27	68.97	31.03	
	5. Prodelles	3rd bed	„	1.40	67.28	32 72	
	6. Vendes	Champlaix	„	1.38	66.08	33.92	
	7. Madie	1st bed	„	1.31	66.05	33.95	
	8. Singles	Guinguette	„	1.32	65.14	34.86	
	9. Lempret	C. de l'air	„	1.35	63.08	36.92	
	Mandailles	Lignite	„	1.29	41.45	58.55	
	Chambeuil	„	„	1.28	40.88	59.12	
†Auvergne, Central France, department of Puy-de-Dôme	1. Charbonnier	Great bed	M. Baudin	1.43	86.41	13.59	
	2. La Combelle		„	1.38	80.31	19.69	
	3. „	La Ronzière	„	1.36	78.82	21.18	
	4. Arnots	Fontaine-du-Chien	„	1.38	77.48	22.52	
	5.	Chamas	„	1.41	76.79	23.21	
	6. Gras Ménil	Great bed	„	1.35	75.31	24.09	
	7. Fondary	Les Vignes	„	1.30	75.15	24.85	
	8. La Taupe	Arrest	„	1.32	73.89	26.11	
	9. Mégécoste	6th bed of 4-ft.	„	1.34	73.01	26.99	
	10. La Taupe	Great mass	„	1.32	71.80	28.20	
	11. Les Barthes	Bastard of 3-ft.	„	1.36	74.40	28.60	
	12.	8-feet bed	„	1.39	70.14	29.86	
	13. Mégécoste	7th bed of 8-ft.	„	1.34	70.09	29.91	
	14. Les Barthes	3-feet	„	1.45	70.07	29.93	
	15. Mégécoste	6-feet bed	„	1.34	69.86	30.14	
	16. Les Barthes	3-feet	„	1.35	68.64	31.34	
	17. Mégécoste	7-feet	„	1.49	67.08	32.92	
	18. Les Barthes	Le Feu	„	1.33	66.78	32.22	
	19. Brioude	Preissat	„	1.32	59.43	40.57	

* Coal of the Bourbonnais, department of Allier. † Coal basin of Brassac.

BITUMINOUS COALS OF FRANCE—(*continued*).

Departments, Coal Basins, and Varieties of Coal.	Locality.	Concessions.	By whom analysed.	Specific Gravity.	Analysis.		
					Carbon.	Volatile Matter.	Ashes.
Basin of Brassac, mines of La Taupe and Arrest	NearGuinguette	Singles . . .	M. Baudin	—	63.90	32.00	4.10
	. . . . .	Agassiz bed .	,,	1.340	65.00	26.40	8.60
	. . . . .	La Louise bed	,,	1.310	68.50	26.80	4.70
	. . . . .	4-feet bed . .	,,	1.320	66.20	27.00	6.80
	. . . . .	La Félicité bed	,,	1.300	67.50	26.00	6.50
	. . . . .	La Trouelle .	,,	1.330	66.10	26.30	6.60
Basin of St. Kloy, or Montaigne	La Roche . .	. . . . .	,,	1.300	59.80	40.20	5.20
	La Vernarde .	. . . . .	,,	1.300	60.40	39.60	8.70
Basin of Bourg Lastic	Messeix . . .	. . . . .	,,	1.390	86.24	13.76	5.20
	Singles . . .	. . . . .	,,	1.380	75.00	25.00	13.00
	,, . . .	. . . . .	,,	1.320	68.00	32.00	8.20

BITUMINOUS COALS OF FRANCE, DEPARTMENT OF PUY-DE-DÔME.

Saône-et-Loire	Puy S. Gulmier	De Chiex . .	M. Baudin	1.340	84.45	15.55	—
	La Besette . .	Vazazène. . .	,,	1.280	66.75	33.25	—
	St. Bérain .	Mellière . .	M. Grüner	—	74.00	—	28.52
		Jumeaux . .	,,	—	68.75	—	22.63
		,, 1st class	,,	—	68.75	—	24.00
		Vignes . . .	,,	—	73 52	—	26.50
		Quatre Bras .	,,	—	66.80	—	19.80
		St. Charles .	,,	—	69.25	—	22.10
Basin of Creusot and Blanzy	Maillot . . .	. . . . .	,,	—	59.50	—	12.20
	Communautés .	. . . . .	,,	—	67.75	—	5.45
	Montchanin . .	. . . . .	,,	—	61.25	—	9.00
	Longue Fendue	. . . . .	,,	—	60.00	—	8.00
	Ragny . . .	. . . . .	,,	—	63 20	—	8.55
	Blanzy . . .	Montceaux. .	,,	—	58.00	—	5 00
	Lucy	Lucy . . .	,,	—	65.00	—	14.00
Saône-et-Loire	Basin of Epinac	. . . . .	Regnault	—	61.10	36.40	2.50
Provence. Basses-Alpes	Volx . . .				51.70	42.50	5.80
	Dauphin . . .				49.20	46 30	4.50
	Volx . . .				39.20	45.80	15.00
	Dauphin . . .				34.70	53.10	12.20
	Sigonce . . .				40.60	52.40	7.00
	Manosque . .				31.20	50.50	18.30
	Villemus . . .				38.90	51.50	9.60
	Pierre-vert . .	Lignites . .	M. Diday	—	28.00	45.80	26.20
Var	Cadière . . .				48.10	44.80	7.10
	St. Zacharie .				32.40	61.60	6.00
	Beausset . . .				40.60	39 40	20.00
Vaucluse	Méthamis . .				40.90	50.00	9.10
	Piolenc . . .				26.60	51 10	22.30
	,, . . .				41.50	52.30	6.20
	Moutragen . .				36.80	48.20	15.00
*Basin of Saint Etienne	Du Soleil. . .	Monteel. . .	M. Grüner	—	74.59	19.60	2.81
	St. Marie . .	Chaney . . 1	,,	—	74.81	21.67	3.52
	St. Claude . .	Méons . . 1	,,	—	74.31	24.17	1.52
	,, . .	,, . . 2	,,	—	73.80	23.13	3.07
	St. Marie . .	Chaney. . 2	,,	—	73.78	24.33	1.89
	Reveux . . .	Reveux . . .	,,	—	72.73	22.83	4.44
	St. Claude . .	Méons . . 3	,,	—	72.13	24.47	3.40
	Caraude . . .	Côte-Thiolière	,,	—	69.13	25.67	5.20
	. . . . .	Grande couche du cros	,,	—	69.27	24.50	6.23

* Fat coals, very rich in carbon first class.

BITUMINOUS COALS OF FRANCE, DEPARTMENT OF PUY-DE-DÔME—(*continued*).

Departments, Coal Basins, and Varieties of Coal.	Locality.	Concessions.	By whom analysed.	Specific Gravity.	Analysis.		
					Carbon.	Volatile Matter.	Ashes.
2nd class. Ordinary Coals of Saint Etienne	Chené. . . .	5. De la Roche	M. Grüner	—	67.96	28.47	3.57
	Vincent . . .	5. Bérard . .	,,	—	66.66	29.20	4.14
	Deville . . .	3. De la Roche	,,	—	65.72	31.90	2 38
	,, . . .	3. ,,	,,	—	61.05	32.54	6 41
	,, . . .	7. ,,	,,	—	66.35	28.27	5.38
	St. André . .	Méons . . .	,,	—	65.68	27.83	6.49
	Pompe . . .	7. Du Treuil .	,,	—	62.89	29.73	7.38
	,, . . .	7. ,, .	,,	—	58.81	26.03	15.16
	Vincent . . .	7. Bérard . .	,,	—	63.71	25.27	11.02
	,, . . .	6. ,, . .	,,	—	63.94	27.13	8.93
3rd class. Fat Coals, longue flamme	Montrambert	Great bed, 1st quality	,,	—	57.82	34.10	0.08
	,, .	2nd ,,	,,	—	54.56	35.43	10.01
	Littes . . .	Beraudière . .	,,	—	58.79	35.57	5.64
	Great bed . .	1st quality . .	,,	—	59.29	35.20	5.51
*Bouches-du-Rhône	Lignites of Greasque	Méne du haut 1	M. Diday	—	48.20	49.00	2.80
		Bleu . . . 2	,,	—	48.50	48.00	3.50
		Menette . 3	,,	—	45.60	46.60	4.80
		Maitre Jean 4	,,	—	41.90	51.60	6.50
		La Fortune 5	,,	—	44.70	52.30	3.00
		La Saoude . 6	,,	—	43.70	47.80	8.50
		La Ravette 7	,,	—	39.10	53.90	7.00
†Ardennes	Séchwal . . .	Peat	M. Sauvage	—	22.00	69.70	8.30
†Basses-Alpes	Lauzanier . .	,, ...	M. Diday	—	9.00	58.00	33.00
*Basses-Pyrénées	Bayonne . . .	Lignite . . .	M. Grüner	—	48.50	38.10	13.70
*Lozère and Aveyron	Rosiers . . .	,, . . .	. . . .	—	50.70	47.60	1.70
	Peyre lau . .	,, . . .	M. Cochon	—	49.10	46.20	4.70
*Gard	Alais	St. Christol, lig.	M. Varin	—	34.00	46.00	20.00
*Bouches-du-Rhône	Rocher Bleu	Great lig'te bed	M. Diday	—	50.20	46.30	3.50
	Belcodène .	Smaller beds of lignite	,,	—	45.20	52.40	2.40
				—	26·50	53.50	20.00
Var	Collobrières . .	Coal	,,	—	63.00	28.00	9.00
‡Coals in Arrondissement of Alais, Department of Gard	La Grande Combe . .	1. Fournier .	M. Varin	—	76.00	16.00	8.00
		2. Plomb . .	,,	—	70.00	17.00	13.00
		3. L. Barraque	. . . .	—	80.50	14.50	5.00
		4. Abilon . .	M. Varin	—	81.00	14.00	5.00
		5. Velours .	. . . .	—	75.00	14.00	11.00
		6. Bosquet .	M. Varin	—	74.00	20.00	6.00
		7. Rothschild	. . . .	—	73.50	16.50	10.00
	Prescol . .	8. Levape .	. . . .	—	77.00	18.00	5.00
		9. Trois-Machoires	M. Varin	—	77.50	18.00	4.50
		10. Cinq-pans .	,,	—	78.00	19.50	2.50
	Partes . .	11. Taranière .	. . . .	—	65.00	18.50	16.50
		12. Rowière .	M. Varin	—	78.50	14 00	7.50
	Bességes . .	13. Great bed .	,,	—	67.50	20.50	12.00
	Champelauzon .	14. Champelauzon	. . . .	—	79.50	13.00	7.50
	St. Jean-de-Valerisle	15. Remise .	M. Varin	—	72.00	9.00	19.00
	St. Paulet . .	16. Lignite .	,,	—	36.50	51.00	12.50
	Connaut . . .	17. ,, .	,,	—	35.00	51.00	14.00
Coal basin of Alais, Department of Gard	1. Bességes . .	Coal	,,	—	68.50	25.50	6.00
	2. Saint Cristol	Lignite . . .	,,	—	34.00	46.00	20.00
	3. Grand Combe	Coal	,,	—	80.50	17.00	2.50
	4. ,,	Pin bed . . .	,,	—	74.00	18.50	7.50

* Lignite beds. † Peat. ‡ Bituminous coals in France.

BITUMINOUS COALS OF FRANCE, DEPARTMENT OF PUY-DE-DÔME—(*continued*).

Departments, Coal Basins, and Varieties of Coal.	Locality.	Concessions.	By whom analysed.	Specific Gravity.	Analysis.		
					Carbon.	Volatile Matter.	Ashes.
Coal basin of Alais, Department of Gard	5. Bessèges	Coal	M. Varin	—	63.00	24.50	12.50
	6. Grand Combe	Plomb	„	—	77.50	19.00	3.50
	7. Cessons	Mean of 3 exp.	„	—	78.30	17 70	4.00
	8. „	Masse bed, 3 ex.	„	—	58.50	26.50	15.00
	9. „	Salze bed, 2 ex.	„	—	83.00	7.50	9.50
	Rochebelle		M. Berthier	—	68.00	21.60	11.40
Hérault	Saint-Gervais basin	Concessions of Bousquet'dorbe and Graissesac 2	M. Garella	—	56.50	17.00	26.50
		3	„	—	77.50	19.00	3.50
		4	„	—	70.50	16.00	13.50
		5	„	—	69.70	15.00	15.40
		6	„	—	65.20	18.50	16.30
		Graissesac		—	68.80	31.20	15.30
		St. Gervais	M. Grüner	—	85.16	14.84	14.05
				—	78.30	16.40	5.30
Aveyron	Basin of Aubin, or Dècazeville	Paleyret, No. 3	M. Senez	—	67.50	26.60	5.90
		„ 4	„	—	61.00	32.80	6.20
		Bouran	„	—	71.50	24.60	3.90
		Fontanges	„	—	63.00	27.20	4.20
		Fareiret	„	—	53.00	38.30	8.70
		Bouquiès	„	—	69.80	25.10	5.10
		Cransac	„	—	53.20	39.30	7.50
		Lavergne	„	—	50 00	42.00	8.00
		Le Poux	„	—	55 00	38.00	7.00
		Lagrange	M. Regnault	—	61.20	34.20	4.60
Tarn	Basin of Carmeaux	Grand-Vein		—	72.60	23.60	3.80
		Castillan		—	74.50	20.90	4.60
Aude	Basin of Ségure		M. Berthier	—	56.00	24.00	20.00
			M. Bois	—	60.00	22.00	18.00
			M. Leplay	—	71.60	24.00	4.40
	Basin of Durban		M. Berthier	—	49.00	33 50	17.50
Nord	Basin of Valenciennes	Anzin, bitumens	Chevalier	1.284	74.25	25.00	0.75
		Fresnes anthre'e	„	1.360	89.30	7.20	3.50
Haute-Saône	Gémonval	Anzin	Berthier	1.284	71.50	25.00	3.50
Vosges	Norroy	Corcelles&Lure	M. Drouot	1.440	48.90	36.60	14.50
			M. Regnault	1.410			
Rhone	Rive-de-Gier	Grand-Croix		1.298	67.20	31.00	1.80
				1.302	68.80	29.80	1.40
		Cimitière		1.288	68.40	28.00	3.60
				1.294	67.00	30 00	3.00
		Couzon		1.298	62.80	34.50	2.70
				1.311	62.10	32.60	5.30
		Corbeyre		1.315	74.00	23.00	7.00
		Couzon	M. Grüner	—	63.55	30 93	5.52
		Grézieux	„	—	62.54	25.10	12.36
		Couzon	„	—	62.57	30.07	7.34
Doubs		Mortean	M. Boyé	—	29.50	53.50	17.00
		Flangebouche	„	—	30.00	62.00	8.00
Jura		Orbagna	„	—	30.50	57.50	12.00

ANALYSIS OF COMBUSTIBLES, EUROPE.

Departments, and Varieties of Coal.	Locality.	Designation of Coal Beds.	By whom analysed.	Analysis.		
				Carbon.	Volatile Matter.	Ashes.
Deux Sévres	Chantonnay . .	Main coal . . .	M. Boyé	62.70	20.00	17.30
Vendee	Basin of Vouvant	Faymoreau . .	M. Berthier	61.15	29 50	6.15
				65.10	27.50	7 40
Loire Inférieure	Ancenis . . .	Guignardière . .	M. Sentis	58.50	31.00	10.50
Finisterre	Plogoff	Cap. Sziain . .	,,	63.00	25·00	12.00
		Pits of St. Barbe .	M. Sentis	80.21	17.00	3.79
				77·59	18.00	4.41
	Layon et Loire	Du Bocage . .	and	82.39	13.20	4.41
		Des Barres . .	M. Lechatelier	67.03	16.60	16.37
		The West . . .	,,	69.92	18.00	12.08
		St. Nicolas . .	,,	65.88	23.40	10.72
	Mont-jean .			73.76	22.34	3 90
France.		Beau-soleil . .	,,	74.02	19.20	6.78
Coals of Maine et Loire	St. Georges sur Loire . . .	The Arch . . .	,,	63.40	27.87	8.73
	Chaudefonds .	St. Barbe . . .	,,	73·57	10.00	16.43
		St. Nicolas . .	,,	71.78	11.60	16·62
		Conception . .	,,	72.71	15.60	11.69
	St. Georges Chatelaison.			65.00	23.80	11.20
		Adèle	,,	80.99	9.40	9.61
		Du Pavé . . .	,,	78.10	18.40	3.50
	Doué	De Minières . .	,,	65.28	27.80	6.92
Haute-Loire	Basin of Langeac	. . . . .	M. Baudin	74.00	26.00	7.10
Feroe Islands	Suderoë I. . .	Brown coal . .	Durocher	24.50	37.50	38.00
	Meissmer . . .	Anthracite . .	M. Kuhnert	70.19	14.34	15.47
Hesse Cassel (Coals)	,, . . .	Pechkohle . . .	,,	56.60	40.97	2.43
	Hirschberg . .	,, . . .	,,	60.83	38.36	0.81
	Habichtwald . .	,, . . .	,,	57.26	35.41	7.33
	Hirschberg . .	Dry coal . . .	,,	66.11	31.13	2.76
	Habichtwald . .	Lignite, passing to coal	,,	54.18	42.49	3.33
Hesse Cassel (Lignite)	,, . .	Inferior lignite .	,,	52.98	42.10	4.92
	,, . .	Middle ,, .	,,	54.96	41.84	3.20
	Rigenkubl. . .	Woody ,, . .	,,	51.70	47.01	1.29
	Stillberg . . .	Lignite . . .	,,	50.78	42.27	6.95
		Peat or turf .	D. Mushet	25.20	72.60	2.20
			Marcher	65.00	22.00	13 00
			,,	37.00	48 co	15.00
	Cossack . .	Country of the Don	Voskressensky	94.23	—	—
Southern Russia	Don	best anthracite				
	Tiflis	Inferior . . .	. . . . .	63.64	—	—
Italy.						
Principality of Monaco	Mentone . . .	Earthy	M. Diday	49.20	29.90	20.90
	Cueva	One-yard coal .	I. T. Cooper	66.00	31.80	2.20
Spain.	Emanuela . . .	Three-yard coal .	,,	67.90	30.90	2·10
Coals of Asturias	Viena Alta . .	Four-yard coal .	,,	63.60	33·90	2.50
	. . . . .	Mine of Clausel .	M. Berthier	35.00	53.00	12.00
	. . . . .	Del Regueron .	,,	43.00	44.00	13.00
	. . . . .	Mean of 5 other mines	,,	53.00	40.00	7.00
	Tudela	. . . . .	M. Pail'ette	65·80	32 27	1.93
	Mieres	. . . . .	,,	57.60	39.40	3.00
	Lama	. . . . .	,,	56.69	41 51	1.80
	Oloniego . . .	. . . . .	,,	60.40	36.55	3.05
	Arnao	. . . . .	,,	45.69	45.11	9.20
	Ferrones . . .	. . . . .	,,	46.98	46.91	6.11

BITUMINOUS COALS IN BELGIUM.

Countries, Provinces, and Varieties of Coal.	Locality.	Designation of Coal Beds.	By whom analysed.	Specific Gravity.	Analysis.		
					Carbon.	Oxygen and Hydrogen.	Ashes.
Province of Hainault.	Dour	. . . . .	Berthier	—	71.50	23.30	5.50
	,,	. . . . .	,,	1.307	88.00	—	2.50
	,,	. . . . .	,,	—	85.00	12.70	2.30
	. . . . .	. . . . .	M. Canchy	1.276	84.67	13.23	2.10
	. . . . .	. . . . .	,,	1.292	83.87	12.47	3.68
	Basin of Mons	Plate seam	M. Chevalier	1.273	—	—	1.98
	,,	. . . . .	,,	1.263	—	—	1.27
Near Mons	,,	. . . . .	Karsten	1.307	85.50	12.00	2.50
	Canton of Dour	. . . . .	Berthier	1.270	71.50	23.30	5.20
	Near Mons	Boulean	,,	1.270	65.30	33.00	1.70
	. . . . .	Grand Gaillet	,,	—	58.50	38.50	3.00
	. . . . .	Gade vein	,,	—	51.00	44.00	5.00
Province of Liége.	Liége	Ste. Marguerite	C. Davreaux	—	78.30	17.80	3.90
				—	76.00	19.60	4.40
	,,	Olisson	,,	—	69.90	23.40	6.70
	,,	Cerisier	,,	—	72.60	24.20	3.20
Dry coals	Harion	L'Harbe St. Michel	M. Delvaux	1.365	68.50	21.20	10.30
	Chokier	Petite Hareng	,,	1.286	81.90	9.00	9.10
	Bonnier	Moset seam	,,	1.318	71.68	16.36	11.96
					91.38	8.00	6.12
GERMANY.							
Bituminous Coals.							
Upper and Lower Silesia	Waldenberg	Glanz coal	Richter	—	57.20	36.40	6.40
	Sabrze	,,	,,	—	63.20	3 .93	3.90
	Bielschowitz	,,	,,	—	58.17	37.89	8.93
	Leopoldinengrübe	,,	Gay Lussac	—	61.50	35.62	2 88
	Friedrich zu Zawada	. . . . .	Karsten	1.263	57.90	42 00	2.10
	Gustaw Grübe	. . . . .	,,	1.270	68.00	30.10	1.90
Saxon States	Sälzer	Newark	.	1.288	81.60	17.70	0.70
	,,	,,	Gay Lussac	—	80.10	18.90	1.00
Prussian Saxony	Circle of the Saale	Wettin or Wittenberg	Karsten	1.466	56 70	18.90	24.40
Germany	Brown coal	Shraplau	. . . .	—	20.25	62.25	17.50
	Eschweiler	Flotz Gyr	Gay Lussac	—	82.40	16.42	1.18
	. . . . .	,,	Karsten	1.300	80.23	18.60	1.17
Saxony	Pottschapel	Gate Schicht	,,	1.454	41.00	31.30	27.70
	Planitz	Pitch coal	,,	1.860	63.40	35.20	1 10
Bohemia	Elbogen	Brown coal	M. Balling	—	37.18	56.16	6.66
	Schlakenwerth	Carbonized peat	M. Debette	—	67.00	30.00	3.00
Würtemburg	Königsbrunn	Raw peat	M. Berthier	—	24.40	70.60	5.00

BITUMINOUS COALS IN ASIA.

Country.	Locality.	Designation of Coal Beds.	By whom analysed.	Specific Gravity.	Analysis.		
					Carbon.	Volatile Matter.	Ashes.
HINDOSTAN.							
Pres. Bengal	Nerbudda . .	Fatepoor . .	. . . .	—	22.00	14.00	64.00
	Chirra Ponoje .	Slaty . . .	. . . .	1.447	41.00	36.00	23.00
Assam	Cossyah or Kosya hills	Few ashes . .	. . . .	1.275	60.70	38.50	0.80
Pres. Bengal	Prov. Delhi . .	Hurdwar . .	. . . .	1.368	50.00	35.40	14.60
Birmese coast	Aracan . . .	. . . . .	. . . .	1.308	33.00	66.40	0.60
Turkey in Asia	Anatolia . . .	Heraclea . .	Prof. Hitchcock	—	62.40	31.80	5.80
Syria	Mount Lebanon	Asphaltum . .	,,	—	24.40	68.00	7.60
	Mount Hermon	Anti-Libanus .	,,	—	14.00	72.60	13.40

ANALYSIS OF AMERICAN COALS.

No.	Locality.	Description of Coal.	Water.	Volatile Matter.	Fixed Carbon.	Sulphur.	Ash.
1	Virginia .	Nelson or Big bed, coking .	0.932	20.738	73.728	0.618	3.924
2	Pennsylvania	Lump coal, Connellsville, do. .	1.260	30.107	59.616	0.784	8.233
3	,,	Slack, do. do. .	0.950	29.662	55.901	1.931	11.556
4	,,	Pittsburg seam, do do. .	—	31.360	59.620	0.784	8.230
5	West Virginia	New River measures, coking .	0.450	18.990	77.970	0.560	2.030
6	,,	Do. do. do. .	0.440	20.060	77.740	0.590	1.170
7	,,	Do. do. do. .	0.380	20.150	74.900	1.360	3.210
8	,,	Do. do. do. .	0.360	20.760	76.890	0.640	1.350
9	,,	Lower measures, do. .	1.030	21.380	72.320	0.200	5.070
10	,,	Do. do. do. .	0.610	22.340	75.020	0.610	1.470
11	Tennessee .	Upper do. (Rockwood), do. .	1.750	26.620	60.110	1.490	11.520
12	Colorado .	Laramie formation . . .	1.140	29.970	56.320	—	12.570
13	,, .	Fox Hill group . . .	0.720	23.440	71.910	0.360	3.930
14	Pennsylvania	Lower Kittaning seam . .	3.000	31.500	62.350	1.400	3.150
		Bituminous Coal of the Cahaba Coal-field.					
15	Alabama .	Cahaba vein	1.660	33.280	63.040	0.525	2.020
16	,, .	Holt's mine	1.580	32.600	62.620	1.050	3.200
17	,, .	Black shale vein . . .	1.910	32.650	63.910	0.630	1.530
18	,, .	Moglis seam	1.930	32.840	59.640	3.780	5.590
19	,, .	Little Pittsburg vein . .	2.050	32.470	62.200	0.641	2.280
20	,, .	Conglomerate do. . . .	2.130	30.860	64.540	1.480	2.470
21	,, .	Helena do.	2.540	29.440	66.810	0.528	1.210
22	,, .	Coke do.	1.780	30.600	66.580	0.564	1.090
23	,, .	Gholson do.	2.140	31.920	63.680	—	2.260
24	,, .	Montevallo do. . . .	2.130	27.030	66.220	0.532	4.620
25	,, .	Gould seam	1.340	28.960	60.580	0.820	9.120
26	,, .	Beaver dam do. . . .	0.300	31.360	65.450	0.080	2.810
27	,, .	Helena mines	1.740	35.480	58.960	0.900	3.820
28	,, .	Wood's pit	0.760	35.510	57.420	—	6.310
29	,, .	Pushmattahaw bed . .	0.790	36.680	57.230	—	5.300
30	,, .	Wadsworth seam . . .	—	34.600	60.530	0.680	4.870
		Bituminous Coals of Warrior Coal-field.					
31	,, .	Townley bed, lower part .	3.007	29.084	63.352	0.710	4.557
32	,, .	Do. upper do. .	2.960	26.162	44.516	1.744	26.362
33	,, .	Jagger bed, lower do. .	2.238	29.037	50.638	0.360	17.987
34	,, .	Do. upper do. .	3.091	29.041	56.537	0.574	11.328
35	,, .	Baker bed, upper do. .	6.355	31.086	60.665	0.695	1.894

ANALYSES OF AMERICAN COALS—(*continued*).

No.	Locality.	Description of Coal.	Water.	Volatile Matter.	Fixed Carbon.	Sulphur.	Ash.
		Bituminous Coals of Warrior Coal-field.					
36	Alabama	Baker bed, lower part	2.578	35.164	59.348	1.331	2.910
37	,,	Phillip and Cordell bed (No. 3)	3.098	34.552	60.745	0.649	1.605
38	,,	Do. (No. 2)	2.052	38.078	55.265	3.070	4.605
39	,,	Jim Hawthorne bed (No. 1)	2.969	29.784	60.598	0.516	6.649
40	,,	Sect. 4, Townsh. 16, Range 6 W.	3.799	26.217	57.316	0.482	12.668
41	,,	Do. 8, do. 15, do.	2.213	28.987	56.454	0.586	12.355
42	,,	Robinson bed, sample 1 (No. 2)	2.454	27.007	57.600	0.580	12.989
43	,,	Do. sample 2 (No. 2)	2.703	26.600	56.367	0.599	14.330
44	,,	Do. do. (No. 1)	1.848	28.365	58.213	0.711	11.574
45	,,	Beechy Hollow bed	6.952	27.065	55.640	0.527	10.343
46	,,	Baley bed, sample 1	2.702	29.564	64.818	0.690	2.916
47	,,	Do. do. 2	5.715	28.095	62.612	0.603	3.578
48	,,	Do. do. 3	1.533	30.405	51.962	1.236	16.100
49	,,	Sect. 24, Townsh. 16, Range 7 W.	4.535	26.407	56.890	1.105	12.218
50	,,	Village Creek bed, upper part	4.175	22.415	62.482	0.521	10.928
51	,,	Do. lower do.	1.525	26.170	66.020	0.604	6.285
52	,,	Newcastle vein	0.800	28.240	59.690	0.640	10.920
53	,,	Black Creek vein, sample 1	0.120	26.110	71.640	0.100	2.030
54	,,	Do. do. 2	1.360	31.796	64.710	0.320	1.820
55	,,	Coketon vein, upper part	1.474	32.288	59.503	1.244	6.735
56	,,	Do. lower do.	1.529	30.683	63.683	0.612	4.102
57	,,	Fork Shoals profile, No. III.	4.976	27.169	62.135	0.793	5.720
58	,,	Do. No. III.	1.475	34.271	59.128	1.131	5.126
59	,,	Do. No. II.	1.442	27.211	66.000	1.506	5.347
60	,,	Do. No. II.	1.398	30.647	62.183	1.076	5.772
61	,,	Do. No. I.	3.560	26.566	64.288	0.722	5.646
62	,,	Cane Hollow bed	1.258	26.253	59.896	1.945	12.594
63	,,	Blue Creek profile, sample 1, No. I.	2.514	32.093	61.886	0.801	3.507
64	,,	Do. do. 2, No. I.	2.179	32.855	59.820	0.608	5.146
65	,,	Do. do. 1, No. II.	0.778	33.271	61.082	0.835	4.869
66	,,	Do. do. 2, No. II.	2.391	33.865	59.069	0.798	4.675
67	,,	Cannel coal, Daniel's Creek	0.830	36.207	48.319	2.752	14.644
68	,,	Block coal seam	2.239	34.606	50.375	1.613	12.780
69	,,	Double do.	1.810	34.029	58.241	2.129	5.291
70	,,	Manby seam	2.004	33.833	61.872	0.752	2.291
71	,,	University seam, J. Black's branch	7.285	28.989	54.522	0.765	9.204
72	,,	Do. University mine	1.833	36.233	54.534	1.038	7.400
73	,,	Do. Goree bed	2.062	31.103	55.495	0.870	11.340
74	,,	Prude's lower bed	5.426	31.952	59.455	0.626	3.167
75	,,	Chambers' mine	1.838	30.682	64.339	2.380	3.141
76	,,	McLester shaft, near Tuscaloosa	2.245	35.130	55.301	1.861	7.324
77	,,	Asylum do. do.	1.892	32.011	55.364	1.867	10.733
78	,,	Burnett bed	3.694	35.380	58.517	1.730	2.409
79	,,	Mineral charcoal	1.753	15.285	79.215	—	3.747
80	,,	Bituminous slate	0.268	75.688	7.284	1.501	16.742
81	,,	Warrior coal	—	32.370	64.990	—	2.640
82	,,	Woodward's coal, N.W. from Wheeling	—	31.244*	63.458	—	5.318
		Kittaning Lower Coal Bed.					
83	Pennsylvania	Glen White Coal Co.	0.940	29.660	59.912	0.978	8.510
84	,,	Do. do.	1.040	28.010	49.244	4.501	17.205
85	,,	Woodvale Bennington	—	22.380	68.500	1.120	8.000
86	,,	Bennington shaft	1.400	27.225	61.843	2.602	6.930
87	,,	Dennison, Porter, and Co.	0.910	26.340	64.373	1.792	6.585
88	,,	Cambria Iron Co.	—	20.330	70 830	2.730	8.830
89	,,	Johnstown Manufacturing Co.	1.185	16.540	74.456	1.860	5.959
90	,,	South Fork Cambria Coke and Coal Co.	1.100	17.240	73.145	2.352	6.163
91	,,	Dysart and Co.	0.615	17.935	76.503	0.602	4.345

* Including moisture.

ANALYSIS OF AMERICAN COALS—(*continued*).

No.	Locality.	Description of Coal.	Water.	Volatile Matter.	Fixed Carbon.	Sulphur.	Ash.
		Kittaning Lower Coal Bed.					
92	Pennsylvania	Lloydsville	0.630	24.230	59.216	2.239	13.685
			0.710	26.065	64.806	1.509	6.910
			0.970	26.130	63.624	2.581	6.695
93	,,	Powelton Coal and Iron Co.	0.540	22.560	71.551	1.079	4.270
94	,,	Do. lower bench	0.600	22.600	68.709	2.691	5.400
		Kittaning Upper Coal Bed.					
95	,,	Hale's	0.740	25.210	68.628	2.122	3.300
96	,,	New Moshannon	1.100	23.070	71.199	0.611	4.020
97	,,	Mapleton	0.700	23.565	68.890	1.715	5.130
98	,,	Laurel Run	0.800	23.260	72.350	0.590	3.000
99	,,	Derby, lower	0.410	22.810	66.690	1.790	8.300
100	,,	Decatur	0.640	24.360	64.082	3.378	7.540
101	,,	Do.	0.820	23.900	69.007	1.373	4.900
102	,,	Morrisdale	0.550	24.090	71.689	0.571	3.100
103	,,	Do.	0.560	25.190	71.013	0.587	2.650
104	,,	Johnstown	—	16.580	76.870	0.472	6.550
105	,,	Do.	1.140	17.180	73.424	1.408	6.848
		Freeport Lower Coal Bed.					
106	,,	Penn	0.810	20.640	74.023	0.507	4.020
107	,,	Franklin	0.670	21.360	74.284	0.435	3.251
108	,,	Do.	—	20.100	76.390	0.190	3.510
109	,,	Eureka	0.780	21.680	73.052	0.688	3.800
110	,,	Do. No. 2	1.150	19.500	77.050	—	2.300
111	,,	Webster	1.630	22.000	72.815	0.425	3.130
112	,,	Stirling	0.710	23.400	72.218	0.532	3.140
113	,,	Moshannon	0.765	20.090	74.779	0.666	3.700
		Upper Freeport Coal Bed.					
114	,,	Coshun	0.160	18.630	74.950	1.400	4.860
115	,,	Lily Station	0.715	22.250	70.518	1.459	5.058
116	,,	Kittaning Coal Co.	1.190	26.975	64.359	2.728	4.750
117	,,	Dennison	0.960	26.400	65.586	2.274	4.780
118	,,	Hugus, Somerset	0.860	16.885	66.055	0.585	15.615
119	,,	Rush, do.	0.450	17.650	55.580	—	26.770
		Pittsburg Coal Bed.					
120	,,	Beachy	1.680	21.010	69.016	0.764	7.530
121	,,	Wilhelm	1.190	21.000	66.907	0.713	10.190
122	,,	Yoder	1.465	21.285	69.677	0.693	6.880
123	,,	Livengood	1.665	22.350	68.774	1.246	5.965
124	,,	Keystone Coal Co.	1.050	19.610	70.239	0.761	8.340
125	,,	Cumberland Co.	1.385	21.470	69.352	0.763	7.030
126	,,	Laylor Hill	1.630	19.965	66.510	0.775	11.120
		Barren Measure Coal Beds.					
127	,,	W. G. Walker	1.945	21.935	68.544	1.161	6.405
128	,,	H. Coleman	2.010	20.535	68.321	0.744	8.390
129	,,	S. P. Fritz	1.625	22.700	67.467	0.803	7.345
130	,,	Weighley	1.000	18.175	53.521	5.384	21.920
131	,,	T. Price	0.870	20.330	68.944	1.176	8.680
132	,,	Ursina (lump)	0.920	22.950	66.999	3.096	6.035
133	,,	Do. (slack)	1.555	23.480	63.483	4.037	7.445
		Somerset County Sub-basin.					
134	,,	Trevorrow's	0.670	14.530	74.800	0.635	9.365
135	,,	Wilts	0.600	15.415	70.632	1.748	11.605
136	,,	Reitz	0.940	19.060	70.659	1.291	8.050
137	,,	Zimmerman's	0.630	15.565	67.420	3.590	12.795
138	,,	Nicholson	0.840	19.820	71.320	1.530	6.490
139	,,	Do.	0.500	17.660	51.430	3.110	27.300
140	,,	Do.	—	22.740	67.090	—	10.170
141	,,	Heinbach	0.780	20.540	69.580	2.140	6.960

SEMI-BITUMINOUS OR DRY COAL—AMERICA.

State and County.	Locality.	Designation of Coal Beds.	By whom analysed.	Specific Gravity.	Analysis. Carbon.	Volatile Matter.	Ashes.
Tennessee	Cumberland Mountains	Kimbrow's vein .	Dr. Troost .	1.450	71.00	17.00	12.00
	"	Gillenwaters . .	" .	1.450	69.00	14.00	17.00
Kentucky	Hawsville .	Splint or cannel coal	Dr. Jackson	1.250	48.40	48.80	2.80
	Caseyville .	Bituminous coal .	Johnson .	1.392	44.49	31.82	23.69

FAT BITUMINOUS COALS IN WESTERN VIRGINIA.—STATE REPORTS.

	County.	Locality.	Designation of Coal Beds.	Analysis. Carbon.	Volatile Matter.	Ashes.
[Upper coal series.]		Clarksburg . . .	Main seams . .	56.74	41.66	1.60
		" . . .	" . .	49.21	45.43	5.36
		Pruntytown . .	" . .	57.60	39.00	3.40
		Morgantown . .	" . .	60.54	37.30	2.14
Lower coals—Valley of the Ohio	Kanawha .	1. Coal creek . .	Judge Summers's bank .	55.55	41.85	2.60
	" .	2. Grand creek . .	" " " .	52.75	43.20	4.05
	Logan .	3. Wolf creek, Big Sandy river	Burning spring . .	47.15	48.00	4.85
	Kanawha .	4. Big Coal river . .	(Lewis') . . .	50.20	47.10	2.70
	" .	5. Three-mile creek .	Cartrell's . . .	45.95	50.30	3.75
	" .	6. Elk river . .	Friend's mines . .	55.90	39.90	5.20
	Logan .	7. Logan Court-house .	Lawson's . . .	58.35	39.50	2.15
	" .	8. Guyandotte . .	Traa fork . . .	56.50	42.00	1.50
	" .	9. Big Sandy river .	Pigeon creek . .	55.00	41.00	4.00

MODERATELY BITUMINOUS COALS IN WESTERN VIRGINIA.

	County.	Locality.	Designation of Coal Beds.	By whom analysed.	Analysis. Carbon.	Volatile Matter.	Ashes.
Formation No. XI. Rogers			Little Sewell Mountain	Wm. B. Rogers	80.24	17.48	2.28
			"	"	77.64	17.36	5.00
		Big Sewell Mn.	Rogers's seam .	"	75.88	22.32	1.80
		E. side W. flank	Tyree's bed .	"	67.84	30.08	2.08
		"	Deem's bed .	"	71.73	27.13	1.14
	Fayette .	Mill creek . .	Paris's bank .	"	71.88	26.20	1.92
		Scrabble creek .	. . . . .	"	63.36	29.04	7.60
		Bell creek . .	. . . . .	"	—	32.16	
		Keller's creek .	Hansford's . .	W. B. Rogers' State Report	60.92	37.08	2.00
		Second seam . .	Storkton's mine	"	74.55	21.13	4.32
		Campbell's creek	Ruffner's 2d sm.	"	55.76	32.44	11.80
	Lower coal series in the Valley of the Kanawha	"	Noyes's seam .	"	64.16	32.24	3.60
		"	"	"	65.64	31.28	3.08
		Cox's creek . .	3rd seam . .	"	51.41	42.55	6.04
		Faure's bank .	Upper seam .	"	53.20	35.04	11.76
		L. Ruffner's bank	" .	"	49.84	44.28	5.88
		Bream's bank .	3rd seam . .	"	57.76	33.68	8.56
		Smither's bank .	. . . . .	"	54.52	29.76	15.76

MODERATELY BITUMINOUS COALS IN WESTERN VIRGINIA—(*continued*).

	County.	Locality.	Designation of Coal Beds.	By whom analysed.	Analysis. Carbon.	Volatile Matter.	Ashes.
	Lower coal series in the Valley of the Kanawha	Hughes's bank .	. . . . .	W. B. Rogers' State Report	62.32	32.88	4.80
		D. Ruffner's bank	Upper seam .	"	57.28	35.08	7.64
		Warth's bank .	. . . . .	"	54.00	39.76	6.24
	Semi-Bituminous, or Dry.						
	Montgomery	Thom's creek .	Strouble's run .	Wm. B. Rogers	80.20	13.60	6.20
		Lewisburg . .	. . . . .	"	78.84	14.16	7.00
	Botetourt	Catawba . . .	. . . . .	"	78.50	16.50	5.00
Hampshire and Hardy Counties—Basins containing the Lower Coal Series	Hampshire	Brantzburg, N. br. Potomac	2 m. above m. of Savage	. . . . .	72.40	19.72	7.88
		Olwer's tract . .	12 feet seam .	. . . . .	79.08	16.28	4.64
	"	Nr. Westernport	Sigler's mine .	. . . . .	82.60	15.76	2.64
	Maryland	Lonaconing . .	12-feet seam .	. . . . .	77.43	19.37	3.20
	"	Abraham's creek	Macdonald's 3rd seam	. . . . .	74.00	18.60	7.40
		1 mile from top of Alleghany	Near Turnpike.	. . . . .	77.12	19.60	3.28
		Vandever's . .	N. W. Turnpike	. . . . .	61.44	14.28	24.28
	Hardy	Kitzmiller's . .	. . . . .	. . . . .	79.76	15.48	4.76
	"	Falls of Stony riv.	Lower seam .	. . . . .	79.16	15.52	5.32
		Abraham's creek	Michael's . .	. . . . .	72.40	15.20	12.40
		Stony river . .	N. of Turnpike .	. . . . .	83.36	13.28	3.36
		Michael's . . .	Upper part . .	. . . . .	45.24	14.96	39.80
Preston and Monzalia Counties—Basins containing the Lower Coal Series	Preston	Kingswood . .	Fairfax's . .	State Reports .	53.77	31.75	14.48
	"	" . .	Middle seam .	. . . . .	65.32	27.77	6.91
	"	" . .	Forman's basin	. . . . .	73.68	21.00	5.32
	"	Deck Hollow, c.	Martin's. . .	. . . . .	65.42	23.42	11.16
	"	Buffalo Lech run	Beatty's. . .	. . . . .	62.56	29.60	7.84
	"	Big Sandy . .	N. Brandon's .	. . . . .	67.60	22.40	10.00
	"	N. Brandonville	Morton's . .	. . . . .	65.28	30.80	3.92
	"	Cheat river, nr. Kingswood	Price's . . .	. . . . .	60.36	25.00	14.64
	"	Big Sandy, W. side	Seaport's . .	. . . . .	66.64	27.12	6.24
	"	Kingswood . .	Hagan's. . .	. . . . .	68.32	26.48	5.20
	"	" . .	. . . . .	. . . . .	67.28	29.68	3.04
	"	Big Sandy basin	W. side Cheat .	. . . . .	60.04	26.88	13.08
	"	Kingswood . .	Creaps . . .	. . . . .	64.24	30.24	5.32
Bituminous Coals in Eastern Virginia, in the Chesterfield, Powhattan, Goochland, and Henrico Basins	South side James river 1	Stonehenge . .	Chesterfield .	. . . . .	58.70	36.50	4.80
	Chesterfield 2	Maidenhead . .	Engine shaft .	. . . . .	63.97	32.83	3.20
	" 3	Heth's pit . .	" .	. . . . .	62.35	37.65	2.80
	" 4	Mill's and Reid's	Creek pit . .	. . . . .	57.80	38.60	3.60
	" 5	Wills's pit . .	. . . . .	. . . . .	62.90	32.50	4.60
	" 6	. . . . .	Green hole shaft	. . . . .	67.83	30.17	2.00
	" 7	Heth's deep shaft	Bottom seam .	. . . . .	53.36	35.82	10.82
	"	"	Middle seam .	. . . . .	66.50	28.40	5.10
	"	"	Top seam . .	. . . . .	61.68	28.80	9.52
	" 8	Powhattan pits .	Finney . . .	. . . . .	59.87	32.33	7.80
	" 9	Winterpock crk.	Cox's mine . .	. . . . .	65.52	29.12	5.36
		Cloverhill, Appottomax river	Slate coal . .	G. W. Andrews	55.00	38.50	6.50
		"	Mean of 4 spec.	Johnson . .	54.83	33.04	10.13
		Richmond coal .	. . . . .	Andrews . .	59.25	32.00	8.75
		Mid Lothian . .	Wooldridge's p.	Johnson . .	61.08	28.45	10.47
		" . .	Mean result, av. size coal	" . .	53.01	33.25	14.74
		Creek Coal Co. .	Mean of 6 trials	" . .	60.30	31.13	8.57

MODERATELY BITUMINOUS COALS IN WESTERN VIRGINIA—(*continued*).

County.		Locality.	Designation of Coal Beds.	By whom analysed.	Analysis.		
					Carbon.	Volatile Matter.	Ashes.
Bituminous Coals in EASTERN VIRGINIA, in the Chesterfield, Powhattan, Goochland, and Henrico Basins	North side of James river 10	Black Heath pits	Mean of 4 spec.	Johnson . .	58.79	32.57	8.64
		Tippecanoe pits .	,,	,, . .	54.62	36.01	9.37
		. . . . .	Randolph's . .	W. B. Rogers' State Report	66.15	30.50	3.35
	11	Coalbrook Dale .	Second seam .	,,	66.48	29.00	4.52
	12	Anderson's pit .	First seam . .	,,	66.78	28.30	4.92
	13	Barr's pits . .	,, . .	,,	70.80	24.00	5.20
	14	,, . .	Second seam .	,,	54.97	22.83	22.20
	15	,, . .	Third seam . .	,,	65.50	24.70	9.80
	16	,, . .	Fourth seam .	,,	56.07	21.33	22.60
	17	Crough's Lower shaft	Upper seam, 110 ft. from surface	,,	64.60	30.00	5.40
		,,	Mean of 4 spec.	Johnson, State Report	67.32	23.96	8.72
	18	Scott's pit . .	. . . . .	,,	60.86	33.70	5.44
	19	Waterloo shaft .	. . . . .	,,	55.20	26.80	18.00
	20	Deep Run pits .	. . . . .	,,	69.84	25.16	5.00
		,, .	Mean of 40 spec.	,,	67.96	21.57	10.47
		Wills's pit . .	Upper vein . .	T. G. Clemson	66.60	28.80	4.60
		Anderson's pit .	Bottom seam .	R. C. Taylor .	64.20	26.00	9.80
		Chesterfield . .	Called natural coke	W. B. Rogers' State Report	80.30	9.98	9.72
		,, . .	,,	,,	70.00	16.00	14.00
		,, . .	,,	Prof. Bailey .	68.00	17.00	15.00
		,, . .	Mineral charcoal	T. G. Clemson	83.30	10.70	6.00

SEMI-BITUMINOUS OR DRY COALS IN THE STATE OF MARYLAND.—THE CUMBERLAND OR FROSTBURG COAL REGION, OCCUPYING A SMALL PART OF PENNSYLVANIA.

State and County.	Locality.	Designation of Coal Beds.	By whom analysed.	Specific Gravity.	Analysis.		
					Carbon.	Volatile Matter.	Ashes.
PENNSYLVANIA.							
Somerset .	. . . . .	1. Hoyman's new 8-ft. bed	W. R. Johnson	1.343	69.90	22.00	8.10
,, .	. . . . .	2 Uhl's upper vein	,,	1.319	75.75	20.20	4.05
,, .	. . . . .	3. Korn's . .	,,	1.386	68.46	20.10	11.44
,, .	. . . . .	4. Schaeffer's .	,,	1.370	70.70	18.80	10.50
,, .	. . . . .	5. Hoyman's 8 feet as above	,,	1.363	71.50	18.30	10.20
,, .	. . . . .	6. Hoyman's 6 feet	,,	1.362	68.54	19.80	11.66
,, .	. . . . .	7. Uhl's 7-feet vein	,,	1.388	68.44	19.50	12.06
,, .	. . . . .	8 Weller's 4 ft.	,,	1.321	69.10	19.99	11.00
,, .	. . . . .	9. Church land vein	,,	1.480	68.56	18.70	12.74
,, .	. . . . .	10. Hardin's vein	,,	1.491	66.36	17.60	16.04
		Mean results of the ten veins	. . . . .	1.382	69.73	19.59	10.68

SEMI-BITUMINOUS OR DRY COALS IN THE STATE OF MARYLAND—(*continued*).

State and County.	Locality.	Designation of Coal Beds.	By whom analysed.	Specific Gravity.	Analysis.		
					Carbon.	Volatile Matter.	Ashes.
MARYLAND							
Alleghany .	Maryland company	Hoffman's mine on main seam	Silliman and Shepard	1.380	82.01	15.00	2.99
,, .	Cumberland coal	,,	W. Hayes (Boston)	—	77.86	15.60	6.54
,, .	Savage river .	,,	Dr. Jones (Washington)	—	78.00	19.00	3.00
,, .	,, .	,,	D. Jackson (Boston)	1.321	77.09	16.05	7.06
,, .	Maryland company	,,	Dr. T. P. Jones (Washington)	1.291	72.50	22.50	5.30
,, .	,,	,,	,,	1.333	81.00	15.00	4.00
,, .	,,	Frost's mine .	Dr. Ducatel .	—	70.00	20.57	9.50
,, .	Dan's mount .	Av. of 40 spec.	Johnson . .	1.311	73.59	16.04	10.37
,, .	Cumberland coal	. . . . .	Prof. Daniel .	—	66.30	19.40	14.30
,, .	,, .	Maryland company	Johnson . .	1.431	67.26	14.42	18.32
,, .	,, .	Frostburg Neff's	,, . .	1.332	74.53	15.13	10.34
,, .	,, .	Howell's estate	Silliman . .	—	76.77	14.66	8.57
,, .	,, .	,,	Prof. Renwick	—	81.00	13.00	6.00
,, .	,, .	Easby's . . .	Johnson . .	1.305	77.25	16.23	6.52
,, .	George's creek	Main vein, Lonaconing	Dr. Ducatel .	1.386	79.25		
,, .	,,	Third coal . .	,, .	1.552	80.08		
,, .	,,	Fourth coal .	,, .	1.584	85.00		
,, .	Lonaconing company	George's creek, thick bed	Johnson . .	1.346	70.75	16.03	13.22
,, .	Maryland company	Eckert mine on main seam	,, . .	1.437	68.56	15.62	15.82
,, .	Frostburg . .	. . . . .	Chilton . . .	—	77.00	12.00	11.00
,, .	,, . .	Mean of 2 anals.	Dr. J. Percy .	—	78.80	9.47	11.73
,, .	Big vein . .	,, 5 ,,	Dr. Higgins .	1.320	88.05	8.54	3.41
,, .	6-feet vein . .	,, 5 ,,	,, .	1.340	86.01	8.68	5.31
,, .	44-inch vein .	,, 5 ,,	,, .	1.390	74.24	7.13	18.63
,, .	Oakland . .	,, 5 ,,	,, .	1.290	73.34	12.54	5.12

FAT BITUMINOUS COALS IN THE STATE OF OHIO.

County.	Locality.	Designation of Coal Beds.	By whom analysed.	Specific Gravity.	Analysis.		
					Carbon.	Volatile Matter.	Ashes.
Portland . .	Talmadge . .	Upson's mine .	W. W. Mather	1.264	53.404	44.298	2.288
Jackson . . .	Lick Township	. . . . .	,,	1.283	49 882	47 327	2.221
,, . . .	Madison ,, .	. . . . .	J. L. Cassels .	1.560	39.950	44.800	14.620
,, . . .	,, ,, .	Cannel coal .	,, .	1.410			
	Carr's Run .	. . . . .	R. C. T. . .	1.270			
	Pomeroy . .	. . . . .	Dr. J. Percy .	—	76.700	18.700	4.600

FAT BITUMINOUS COALS IN PENNSYLVANIA.

County.	Locality.	Names of Coal Seams.	By whom analysed.	Specific Gravity.	Analysis.		
					Carbon.	Volatile Matter.	Ashes.
Venango .	Shippensville .	Sandy Ridge .	H. D. Rogers' State Report	—	49.80	43.20	7.00
,, .	6 M. F. of Franklin	. . . . .	,,	—	29.54	52.78	17.68
Beaver . .	Greersburg .	. . . . .	,,	—	30.12	36.00	33.88
Crawford .	Conneautville .	. . . . .	,,	—	59.45	38.75	1.80
Mercer . .	Greensville .	. . . . .	,,	—	57.80	40.50	1.70
	,, .	. . . . .	R. C. Taylor .	1.275	—	—	—
	Orangeville .	. . . . .	State Report .	—	53.45	43.75	2.80

MODERATELY BITUMINOUS, DRY, AND CLOSE BURNING COALS IN PENNSYLVANIA.

County or District.	Locality.	Designation of Coal Beds.	By whom analysed.	Specific Gravity.	Analysis.		
					Carbon.	Volatile Matter.	Ashes.
Tioga or Blossburg Coal-field	Blossburg . .	Coal Run, upper vein	Taylor and Clemson	1.371	75.40	16.40	8.20
	,, Bear creek	Clement's coal	,,	1.398	73.74	15.00	11.26
	,,	Bloss's coal .	,,	1.405	73.00	15.60	11.40
	,,	,, .	State Report .	—	62.80	32.80	5.20
	,, Johnson's Run	Splint coal .	Taylor and Clemson	1.493	69.30	14.60	16.10
	,, Coal Run	Slaty variety called cannel	,,	1.750	33.40	8.40	58.20
	,, ,,	Pitch coal . .	,,	1.500	54.26	18.50	27.24
	Head of Tioga	New Hope vein	R. C. Taylor .	1.429	—	—	—
	Arbon company	Coal run, mean of 4 specimens	Johnson . .	1.323	73.11	16.12	10.77
Ralston and Lycoming Creek District	Ralston . .	Big vein . .	State Report .	—	74.50	20.50	5.00
	,, . .	,, . .	Johnson . .	1.387	71.54	14.50	13.96
	Queen's Run .	Av. of 40 specim.	,, . .	1.331	73.44	18.81	7.75
	,, .	. . . . .	State Report .	—	73.68	21.50	4.60
Bradford or Towanda Coal-field	Schroeder, branch of Towanda creek	Lower bed in three parts	W. R. Johnson	1.515	62.60	15.00	22.40
				1.448	70.00	17.40	12.60
				1.465	63.90	19.10	17.00
	,,	Miller's old coal drift	,,	1.377	68.10	20.50	11.40
				1.378	65.50	19.20	15.30
				1.349	74.97	19.30	5.73
	,,	Mason's coal, upper part		1.388	—	—	—
		lower part	,,	1.400	—	—	—
Centre county	Snow-shoe .	. . . . .	State Report .	—	76.73	21.20	2.07
,,	Farrandsville .	Select portion of Diamond vein	Bache and Rogers	1.339	—	—	5.50
,,	Lick Run . .	. . . . .	State Report .	—	66.21	20.72	13.07
Clearfield county	Karthaus . .	. . . . .	W. R. Johnson	1.263	68.15	26.80	5.05
,,	,, . .	Salt Lick . .	,,	1.292	80.49	12.83	6.68
				1.275	76.64	22.27	5.09
,,	,, . .	Upper seam .	State Report .	—	78.20	13.00	8.80
,,	,, . .	Lower seam .	,,	—	70.50	24.80	4.70
,,	Curwensville .	Reed's vein .	,,	—	67.70	27.00	5.30
,,	Caledonia . .	. . . . .	,,	—	54.50	37.00	8.50
,,	,, . .	. . . . .	,,	—	54.60	38.20	2.70

MODERATELY BITUMINOUS, DRY, AND CLOSE BURNING COALS IN PENNSYLVANIA—(*continued*).

	County or District.	Locality.	Designation of Coal Beds.	By whom analysed.	Specific Gravity.	Analysis.		
						Carbon.	Volatile Matter.	Ashes.
Semi-bituminous Coals in Pennsylvania		Karthaus .	Main or 6-ft. seam	W. R. Johnson	—	68.15	26.80	5.05
		Philipsburg .	Best coal . .	W. R. Johnson and R. C. T.	1.308	70.00	22.30	7.70
		,, .	,, . .	State Report .	—	64.40	29.50	6.10
		,, .	,, . .	Dr. Goddard .	1.360	70.00	20.00	10.00
	Moshannon district	near ,, .	Showalter's 3-ft. vein	R. C. Taylor .	1.358			
		,, ,, .	Goss's 6-ft. vein	,, .	1.357			
		,, ,, .	Coal hill . .	,, .	1.500			
		16 miles . .	Steed's mine .	State Report .	—	68.40	20.40	11.20
		17½ ,, . .	Leech's mine .	,, .	—	67.93	20.32	11.75
	Cambria	Blair's Gap .	Portage Rail R.	T. G. Clemson	—	77.00	15.00	8.00
	,,	,, .	Mineral charcoal	,, .	—	66.40	6.60	27.00
	,,	,, .	Large Bed . .	State Report .	—	65.00	31.00	4.00
	,,	Summit .	Portage Rail R.	Johnson . .	1.406	69.59	21.36	9.05
	Dauphin	Short Mn. .	South drift . .	Dr. Ellet, R.C.T.	1.330	75.50	15.30	9.20
				J. C. Booth .	—	—	16.90	
	,,	,, .	Big Flats vein . .	M. C. Lea . .	—	71.20	17.32	13.46
				R. C. Taylor .	1.395			
				Rogers' Reports	—	76.94	15.06	8.00
				J. C. Booth .	—	—	15.80	
				M. C. Lea . .	1.391	78.80	13.20	8.00
	,,	Rattling Run Gap . .	Perseverance vein . .	,, . .	—	76.10	16.90	7.00
				Rogers' Reports	—	74.55	13 75	11.70
				Johnson . . mean of 6 exps.	1.531	72.22	14.29	11.49
	Lebanon	Yellow Springs	Back bone vein	H. C. Lea . .	1.389	74.70	14.80	10.50
				J. C. Booth .	—	—	8.10	
				M. C. Lea . .	1.391	80.33	8.86	10.80
	,,	,,	Kugler vein	,, . .	—	81.20	9.80	9.30
				,, . .	1.395	77.50	11.00	11.50
				Rogers' Reports	1.410	79.55	10.95	9.50
	,,	Cold Spring .	Six-feet vein .	H. Lea . . .	1.403	76.30	11.10	12.60
	Bedford	Broad Top M.	Riddle's bank .	Clemson . .	1.700	70.10	16.70	13.20
	,,	,,	Hopewell . .	Rogers' Reports	—	84.80	11.20	4.00
	,,	,,	. . . . .	W. R. Johnson	—	77.60	16.00	6.40
Soft, free burning Red Ash, Anthracite in Pennsylvania. Coal seams of the South Mn.	Dauphin	Lykens Valley	Bear Gap mines	R. C. Taylor .	1.318			
	,,	,,	1st sample . .	W. R. Johnson	1.391	87.95	7.60	4.45
	,,	,,	2nd ,, . .	,,	1.404	89.30	5.95	4.75
	,,	,,	3rd ,, . .	,,	1.416	85.70	10.00	4.30
	,,	,,	4th ,, . .	,,	1.374	88.70	4.60	6.70
	,,	,,	5th ,, . .	,,	1.376	87.75	8.35	3.90
	,,	,,	6th ,, . .	,,	1.395	88.65	8.30	3.05
	,,	,,	7th ,, . .	,,	1.382	87.20	7.84	4.15
	,,	,,	8th ,, . .	,,	1.398	83.99	11.85	4.15
	,,	,,	9th ,, . .	,,	1.378	87.00	7.30	5.70
	,,	,,	Mean of 9 smpls.	,,	1.390	87.36	8.06	4.57
	,,	,,	Third Beb . .	H. D. Rogers' Report	—	88.25	8.85	2.90
	Schuylkill	Lower Mohantongo	Klinger's or Rausch Gap	J. R. Chilton, M.D.	—	89.71	4.48	5.81

ANTHRACITE OF PENNSYLVANIA.

Description and Localities of Anthracite Coal Beds.		By whom examined or analysed	Specific Gravity.	Analysis of 100 Parts of Anthracite.		
				Carbon.	Water, Hydrogen, and Volatile Matter.	Ashes, Silica, Earthy Matter, Iron, &c.
	Hard, White Ash Coal.					
Schuylkill Eastern Region	Mauch Chunk	Olmsted	1.550	90.10	6.60	3.30
	,,	Vanuxem	1.494			
	,, Summit Mines	W. R. Johnson	—	92.30	6.42	1.28
	,, ,,	Karsten	—	86.00	8.00	6.00
	,, ,,	M. C. Lea	—	87.00	7.30	5.70
	,, 14-feet vein	Rogers' Reports	—	88.50	7.50	4.00
	,, hardest variety	,,	—	87.70	6.60	5.70
	,, mean of 2 results	Dr. J. Percy	—	92.60	5.15	2.25
	Nesquehoning	Taylor	1.558			
	,, 10-feet vein	Rogers' Reports	—	86.60	6.40	7.00
	Tamaqua vein, D. east	M. C. Lea	—	91.00	5.50	3.50
	,, D. ,,	Rogers' Reports	1.570	92.07	5.03	2.90
	,, E. ,,	,,	1.600	89.20	4.54	6.26
	,, R. ,,	,,	1.550	87.45	7.55	5.10
	Tuscarora	,,	—	88.20	7.50	4.30
	Forest Improvement, av. of 4 spec.	Johnson	1.477	92.12	4.83	3.05
Middle Coal-field	Hazleton	Taylor	1.550			
	Sugar Loaf Mountain	W. R. Johnson 3 samples	1.591	88.18	6.99	4.83
			1.574	85.91	5.36	8.73
			1.550	90.70	7.06	2.24
	Beaver Meadow	Taylor	1.600			
	,,	W. R. Johnson	1.630	85.34	9.60	5.06
	,,	,,	1.560	91.64	6.89	1.47
	,,	,,	—	92.30	6.42	1.28
	Girardville	Taylor	1.600			
	Broad Mountain, W. W. Branch	,,	1.700			
Pine Grove District	Big vein, Lorberry creek	,,	1.472			
	,, ,,	M. C. Lea	—	85.90	7.20	6.90
	Locust Mount Coal and Iron Co.	Blake (Boston)	—	96.77	—	3.33
Red Ash coal	Sharp Mountain	Rogers' Reports	1.540	80.57	7.15	3.28
Red Ash—free burning coal, with slight flame.	Black Spring Gap, 4-feet vein	Taylor	1.528			
	,, ,,	Rogers' Reports	1.440	82.47	9.53	8.00
	,, Peacock vein	Taylor & M.C.Lea	—	88.60	7.10	4.30
	,, Grey vein	M. C. Lea and Taylor	1.379	86.00	4.50	9.50
			1.395			
	,, the black compact part	Rogers' Reports	1.440	81.02	9.78	9.20
	,, the grey central part	,,	1.330	81.40	11.40	7.20
—	,, Fishback vein	M. C. Lea	—	84.00	6.50	9.50
Stony Creek Estate, Lebanon Co.	,, Lea vein	Rogers' Reports	1.350	85.84	8.96	5.20
	Gold Mine Gap, Peacock vein	M. C. Lea	—	83.00	9.00	8.00
	,, ,,	Rogers' Reports	1.410	83.15	10.95	6.90
First Coal-field	,, Heister vein	,,	1.410	81.47	10.43	8.10
	Rausch Gap	M. C. Lea	—	78.90	11.00	10.10
	,, Pitch vein	R. C. Taylor	1.387			
	,, Heister vein	,,	1.454			
		M. C. Lea	—	77.10	10.90	12.00
		Rogers' Reports	1.450	77.23	10.57	12.30
White Ash Coal.	Broad Mountain	Dr. C. T. Jackson	1.593	—	—	7.80
	Lehigh or Summit Company, 1st	W. R. Johnson	1.613	87.48	7.51	5.01
	,, ,, 2nd	,,	1.594	91.69	4.31	4.00
—	,, ,, 5th	,,	1.612	86.06	9.23	3.71
South and Middle Coal-field	Mauch Chunk	Dr. J. Percy	—	84.98	4.82	10.20
	Buck Mountain	W. R. Johnson	1.559	91.02	5.90	3.08
	Shamokin (Snyder's)	Rogers' Reports	—	89.80	6.10	4.00
	West Mahanoy	Taylor	1.371			

ANTHRACITE OF PENNSYLVANIA—(*continued*).

Description and Localities of Anthracite Coal Beds.		By whom examined or analysed.	Specific Gravity.	Analysis of 100 Parts of Anthracite.		
	Hard, White Ash Coal.			Carbon.	Water, Hydrogen, and Volatile Matter.	Ashes, Silica, Earthy Matter, Iron, &c.
White Ash Coal. — North or Wyoming Coal-field	Wilkesbarre, Blacksmith's coal	Taylor	1.472			
	,, Warden's vein	Rogers' Reports	1.403	88.90	7.68	3.49
	Wyoming	J. F. Frazer	—	91.20	4.50	4.30
	Lackawanna	Dr. C. T. Jackson	1.609	79.20	9.20	11.60
	,, mean result	Johnson	1.421	88.98	6.36	4.66
	Scranton anthracite	Prof. H. D. Rogers	—	87.88		
	Carbondale	Rogers' Reports	1.404	90.23	7.07	2.70
Red Ash Coal. — Pottsville District. First or South Coal-field	Peach Mountain, Delaware Co.	Taylor	1.446			
	,, mean of 40 spec.	Johnson	1.464	86.09	6.96	6.95
	,, N. American Co.	Dr. C. T. Jackson	1.569	—	—	7.20
	Peach Orchard	,,	1.532	—	—	6.60
	Salem vein	Taylor	1.574			
	Plumbago vein, Sharp Mount	,,	1.412			
	Black Mine vein	H. Lea	—	88.40	6.80	4.80
	Gate vein	Dr. C. T. Jackson	1.609	—	—	6.60
	Shenoweth vein	Rogers' Reports	1.500	94.10	1.40	4.50
	Nealey's Tunnel, 3rd vein	,,	1.550	89.20	5.40	5.40

ANTHRACITES OF THE UNITED STATES.

Description of Coal Beds.			Details.		Analysis of 100 Parts of Anthracite.		
State.	Locality of Mines.		By whom examined or analysed.	Specific Gravity.	Carbon.	Water, Hydrogen, and Volatile Matter.	Ashes, Silica, Earthy Matter, Iron, &c.
Rhode Island	Portsmouth mines		Dr. C. T. Jackson	1.850	85.84	10.50	3.66
	,, ,,		,,	—	87.50	7.00	5.50
	,, ,,		,,	—	77.50	13.00	9.50
	,, ,,		,,	1.770	84.50	10.00	5.50
	,, ,,		L. Vanuxem	—	90.03	4.90	5.07
	,, ,,		,,	—	77.70	6.70	15.60
	Cumberland ,,		Dr. C. T. Jackson	—	77.00	7.60	15.40
	,, ,,		,,	—	39.70	7.80	52.10
	Providence ,,		,,	—	72.00	—	28.00
	Portsmouth old mine		,,	—	74.00	10.00	16.00
	Case's mine		,,	—	97.00	—	3.00
Massachusetts	Man field mine		,,	1.690	87.40	6.20	6.40
	,, ,,		,,	1.780	92.00	6.00	2.00
	,, ,,		,,	1.710	92.00	6.00	2.00
	Worcester plumbaginous anthrac.		Dr. J. Percy	—	28.35	3.08	68.57
North Carolina	Near Leakesville, middle secondary rocks		W. B. Rogers	—	83.12	7.76	9.12
*England	Brrowdale	Plumbago	L. Vanuxem	—	83.37	1.23	10.40
*Pennsylvania	Bustletown		,,	—	94.40	0.60	5.00
*England	Cornwall		Saussure	—	95.00	—	4.00

* Mr. Vanuxem adds, by way of comparison, the analysis of three varieties of plumbago or graphite.

BITUMINOUS COALS.

State and County.	Locality.	Designation of Coal Beds.	By whom analysed.	Specific Gravity.	Analysis.		
					Carbon.	Volatile Matter.	Ashes.
INDIANA :—							
Parke county	Sugar creek .	Foundry . .	D. D. Owen .	1.219	75.00	21.00	4.00
Vermilion .	Brouillet's creek	. . . . .	,, .	1.270	52.00	39.00	9.00
Vigo . . .	Honey creek .	. . . . .	,, .	1.240	70.00	27.50	2.50
Sullivan . .	Busseron . .	Lick Fork . .	,, .	1.240	70.00	28.00	2.00
Fountain .	Wabash . .	Coal creek mouth	,, .	1.260	60.00	25.00	25.00
Spencer . .	Anderson creek	. . . . .	,, .	1.270	45.00	—	—
	White river .	. . . . .	,, .	1.270	56.40	—	—
	Terre Haute .	. . . . .	,, .	1.240	50.80	—	—
	Cannelton . .	Cannel coal .	W. R. Johnson	1.272	59.47	36.59	3.94
ILLINOIS . .	Rock river .	Coal . . .	Dr. D. D Owen	1.340	45.50	44.50	10.00
	Vermilion . .	Danville . .	A. Morfit . .	—	48.50	47.20	4.30
	Western port .	. . . . .	Johnson . .	1.290	—	32.80	—
	Ottawa . .	. . . . .	J. F. Frazer .	—	62.60	35.50	1.90
	Rockwell . .	. . . . .	C. U. Shepard	1.273	46.50	47.50	6.00
IOWA . . .	Duck creek .	W. bank of the Mississippi river	Dr. D. D. Owen	1.270	48.50	44.00	7.50
MISSOURI .	Cote-sans dessein,	Mastodon vein, forty-six feet thick . .	Booth and Boye J. R. Chilton, M.D. . .	—	46.83	40.05	13.12
	Calloway co.	Mammoth vein, twenty-four feet	,, . .	1.252	50.81	34.06	15.13
	Osage river .	. . . . .	W. R. Johnson	1.250	50.78	34.20	15.02
ARKANSAS .	Johnson county	Spalpre's bluff	J. F. Frazer .	1.200	51.16	43.50	5.34
MAINE . . .	. . . . .	Peat . . .	Dr. Jackson .	1.396	62.60	28.90	8.50
Miscellaneous Analyses.				—	21.00	72.00	7.00
Isle of Cuba .	Near Havana .	Asphalt . .	T. G. Clemson	1.190	34.97	63.00	2.03
	Near Matanzas	Asphaltum .	,,	—	—	—	13.50
South America	Peru . . .	Coxitambo .	M. Boussingault	—	—	—	—
	Chili . . .	Arauco . . .	W. R. Johnson	1.324	67.62	30.00	2.38
	Brazil . . .	. . . . .	Karsten . .	1.289	57.90	40.50	2.60
	,, . . .	. . . . .	,, . .	1.483	38.10	33.50	28.40
Madeira Island	Brown coal .	Or lignite . .	Johnstone . .	—	—	—	20.05
BRIT. AMERICA Bituminous coal.							
Nova Scotia .	Pictou . .	Cunard's sample	Johnson . .	1.325	60.73	26.76	12.51
		Mining Associa'n	,, . .	1.318	56.98	29.63	13.39
Cape Breton .	Sydney . . .	Mean of 2 species	,, . .	1.338	67.57	26.93	5.50

ANALYSES OF NEW ZEALAND COALS EXHIBITED AT INDIAN AND COLONIAL EXHIBITION, LONDON, 1886.*

Description of Coal and Locality.	Water.	Volatile Hydro-carbons.	Fixed Carbon.	Ash.	Evapo-rative Power.
Anthracite from Acheron, Canterbury . .	1.80	2.06	84.12	12.12	5.17
Altered brown coal, Malvern Hills, Canterbury	4.15	19.89	68.54	7.42	8.87
,, ,, ,,	12.65	32.04	53.29	2.02	6.92
Brown coal, Malvern, Canterbury . .	11.79	35.42	49.99	2.80	6.49
,, (Homebush Colly.) Malvern, Canterbury	19.20	30.92	47.70	2.20	6.20
Glance coal, Rakaia Gorge, Canterbury .	6.76	21.27	64.51	7.46	8.30
Brown ,, ,, ,, .	24.09	21.61	50.12	4.18	6.50

* See "Jour. Iron and Steel Inst.," vol. i. 1886, p. 246.

ANALYSES OF NEW ZEALAND COALS—(*continued*).

Description of Coal and Locality.	Water.	Volatile Hydro-carbons.	Fixed Carbon.	Ash.	Evapo-rative Power.
Bituminous coal, Grey River, Westland .	1.99	29.44	62.37	6.20	8.01
Pitch coal, Black Creek, Grey River, Westland	8 01	29.97	60.20	1.82	7.82
„ Grey River, Westland . .	6.20	55.40	34.80	2.60	4.56
Bituminous coal, Preservation Inlet . .	4.33	20.69	60.88	6.19	7.91
„ Westport	3.97	32.14	59.75	4.14	7.76
„ Mokihinui, Westport . .	3.16	38.86	55.59	2.39	7.20
Brown coal, Westport	2,60	37.17	56.01	4.22	7.28
„ „	3.96	34.94	57.92	3.18	7.50
Bituminous coal, Brunner mine . . .	1.59	35.68	56.62	6.11	7.36
„ Otamatawea Creek . .	2.19	36.63	52.89	8.29	7.90
Black coal, Kawa River	4.18	42.63	50.15	3.04	6.52
Glance coal, Whangaree, Auckland . .	8.01	38.68	50.11	3.20	6.50
Pitch coal, Kama Mine, Whangaree, Auckland	9.61	37.69	50.01	2.69	6.50
„ Walton's „ „ „	7.20	41.20	38.80	12.80	4.96
Brown coal, Waikato, Auckland . . .	19.82	29.97	50.01	2.20	6.50
Bituminous coal, near Cape Farewell . .	2.18	43.17	48.59	6.06	6.63
Brown coal, Shag Point, Otago . . .	19.20	30.10	45.30	5.40	5.66
„ Kaitangata „	15.44	38.32	44.11	2.13	5.74
„ „ „	19.61	27.25	39.41	3.73	5.12
Bituminous coal, S. of Ross, Southland .	6.58	31.43	42.53	19.46	4.16
Brown coal, Okoko, Waipa, Auckland . .	22.21	33.74	39.83	4.22	5.17
„ Springfield Colliery . . .	18.60	31.50	38.00	11.90	4.90

For remarks on the coal-fields of Australasia, see "Jour. Iron and Steel Inst.," vol. i. 1884, p. 219.

ANALYSIS OF NEW SOUTH WALES COALS.

Locality.	Hygro-scopic Moisture.	Volatile Hydro-carbons.	Fixed Carbon.	Ash.	Sulphur.	Specific Gravity.
Lake Macquarie	3.80	23.90	55.50	6.80		
Goulburn	2.18	30.98	58.04	8.80	0.228	1.35
Goose Valley	3.60	29.70	59.70	6.96	0.050	1.34
„ „	3.66	30.38	54.46	11.50	0.062	1.38
Dora Creek	3.04	17.76	62.10	17.10	0.142	1.44
„ „	2.52	30 48	53.36	13.64	0.140	1.43
Wangenderry	1.74	31 06	52.00	15.20	0.300	1.38
Bowenfels	2 45	28.55	48.56	20.44	—	1.33
Ulladulla	1.50	33.04	57.40	8.06	1.110	1.31
„	1.76	32.06	56.38	9.80	1.240	1.35
Capertee	3.25	25 41	60 24	11.10	0.390	1 39

ANALYSIS OF COAL FROM ZWICKAU (SAXONY), BY BRÜCKNER.

Locality.	100 Parts of Dry Combustible at 212° F. yield:						Raw Combustibles contain Water per cent
	Carbon.	Hydrogen.	Nitrogen.	Sulphur.	Oxygen.	Ash.	
Russkohle Bürgerschacht .	82.10	5.34	0.65	0.37	10.45	1.09	8.00
Pechkohle „ .	80.00	5.50	0.88	0.40	11.54	1.68	8.00
„ Auroraschacht .	73.85	4.70	0.60	0.48	14.10	6.97	6.00

ANALYSIS OF COAL FROM HUNGARY, BY NENDTVICH.

Locality.	100 Parts of Dry Combustible at 100° C. contain:					Water in Raw Combustibles per cent.	Coke.	Specific Gravity.
	Carbon.	Hydrogen.	Sulphur.	Oxygen and Nitrogen.	Ash.			
COMITAT CRASSOE:—								
Pit, Heil Dreifalt . .	83.84	4.36	0.38	11.79	8.24	3.19	78.07	1.390
„ Anton and Joseph .	81.57	4.41	0.87	14.01	2.26	3.21	69.98	1.319
„ Emilia	78.37	3.92	0.74	17.70	1.55	7.30	70.60	1.366
„ Von Resicza . .	88.72	4.66	0.86	6.61	0.89	1.20	78.85	1.295
COMITAT BARANY AND TOKAY:—								
Fünfkirchen, Makay . .	89.99	4.23	1.89	5.78	18.23	1.22	89.40	1.414
„ Paulovics .	88.85	4.23	0.99	6.92	2.85	1.14	83.14	1.300
COMITAT GRAN AND COMORN:—								
Fünfkirchen, Magyaros .	69.21	4.50	3.07	26.28	8.34	13.63	56.84	1.420
„ Ujfalu . .	69.72	4.82	5.10	25.45	9.74	13.60	60.26	1.430

ANALYSIS OF COAL AND BROWN COAL FROM HUNGARY, BY NENDTVICH.

Locality.	100 Parts of Dry Combustible						Water per cent. at 110° C. on Raw Fuel.	Specific Gravity.
	Contain:				Leave:			
	Carbon.	Hydrogen.	Sulphur.	Oxygen.	Ash.	Coke.		
HUNGARY:—								
Coal, Baranyer Comitat, Rosman's pit	86.88	4.37	8.74		10.690	86.47	—	1.356
„ Do., Andrassevich pit, Fünfkirchen	88.30	4.80	6.90		5.820	82.82	—	1.313
„ Barbara pit, Szabolcs . .	89.69	5.03	5.27		10.330	81.55	—	1.350
„ Francis pit „ . .	83.76	4.97	11.26		10.415	77.81	—	1.378
„ Michael's pit, Vassas . .	88.76	5.04	6.20		9.910	76.82	—	1.291
„ University domain, Vassas .	86.72	5.09	8.19		12.050	78.57	—	1.339
„ Purkari pit, Crassöer Comitat	85.29	5.05	9.65		1.605	73.11	—	1.317
„ Gerlistye pit „	85.48	4.92	9.59		2.395	70.96	—	1.282
„ Markus pit „	84.54	4.96	10.50		2.615	68.17	—	1.287
„ Simon and St. Antony pit, Crassöer Comitat . .	82.54	4.35	13.10		10.530	76.33	—	1.423
Brown Coal, Tokodt } Gran	67.49	4.70	27.80		10.990	68.70	—	1.494
„ Coolnok } Comitat	71.55	5.19	23.25		5.660	—	—	1.359
„ Sárisáp }	67.85	4.93	27.22		9.410	61.23	—	1.403
„ Zsemle, Comorn Comitat	71.89	4.79	23.31		4.350	59.55	—	1.347
„ Rudolphi seam 1 } near Oedénburg	70.84	4.71	0.91	24.44	2.390	50.89	18.68	1.285
„ „ „ 2 }	72.18	5.18	0.55	22.63	2.080	55.98	17.00	1.300
„ Joseph „ 3 }	72.49	5.17	1.30	22.33	2.255	53.00	17.82	1.289
„ „ „ 4 }	71.36	5.09	1.63	23.54	4.645	46.00	17.10	1.334

ANALYSIS OF WOOD, TURF, AND BROWN COAL FROM SAXONY, BY BAER.

Kind of Fuel.	100 Parts of Dry Fuel contain: Carbon.	Hydrogen.	Sulphur.	Oxygen.	Ash.	Water per cent. lost at 100° C. by Fuel in Natural Condition.
Birch wood	48.89	6.19	—	43.93	0.99	13.14
Red beech wood	46.10	5.79	—	46.87	1.24	14.4 to 13.6
„ „	48.29	6.00	—	45.14	0.57	13.7
White beech wood	48.08	6.12	—	44.93	0.87	12.8
Oak	48.94	5.94	—	43.09	2.03	8.0
„	48.63	5.94	—	44.75	0.68	13.7
Pine, young stems	50.62	6.27	—	42.58	0.53	12.1
„ old floated stems	49.87	6.09	—	43.14	0.63	11.9
Turf, from Buchfeldt and Neulangen, 1st kind	51.54	4.69		33.90	9.87	15.7
„ „ do., 2nd „	50.13	5.36		35.24	9.37	21.7
„ „ Flatow, 1st kind	50.36	4.20		34.27	11.17	18.4
„ „ Linum, 2nd „	53.69	4.84		31.73	9.74	16.4
„ „ „ 3rd „	55.01	4.63		31.44	8.92	18.9
Brown coal or lignite, from Schönfeld, near Aussig, Bohemia	61.20	5.17		21.28	12.35	21.2
Do., from Fürstenwalde, Rauen, moulded	55.59	4.16		19.06	21.19	11.0

ANALYSIS OF GERMAN COALS.

Locality.	100 Parts of Coal contain: Carbon.	Hydrogen.	Oxygen.	Nitrogen.	Sulphur.	Ash.	Specific Gravity.	Water per cent. in Raw Fuel.	By whom analysed.
HESSE:—									
Coal from Meismer	82.00	4.20	5.90		3.90	4.00	1.307	—	Graeger
„ „	62.18	5.47	18.05		9.30	5.00	1.208	—	
„ „	58.90	5.36	21.63		6.64	7.50	1.079	—	
„ Hirschberg	72.90	5.70	18.40		0.70	2.30	1.289	—	
„ „	62.90	5.70	17.00		7.80	6.60	1.050	—	
„ Faulback	60.60	5.50	18.40		8.00	7.50	1.130	—	
„ Gluckauf, near Mulhouse	36.65	3.84	12.32		—	47.19	2.500	—	
„ „	36.56	5.00	11.25		—	47.19	—	—	
„ Gallery d'Oppel	62.00	4.40	10.06	—	—	6.25	—	6.75	Koettig
„ „	62.35	4.50	11.90	—	—	9.05	—	7.20	
„ „	61.85	4.40	11.85	—	—	15.30	—	7.60	
„ Gallery de Doehlner	61.10	9.10	4.50	—	—	8.55	—	6.75	
„ „	60.10	11.00	4.45	—	—	12.25	—	7.20	
„ „	54.20	9.10	4.45	—	—	24.95	—	7.60	
Anthracite, Schoenfeld	64.68	5.31	21.36	—	—	8.65	—	—	
„ Grosspriessen	63.56	4.81	25.12	—	—	6.51	—	—	
Coal, Grosspriessen	74.57	5.33	12.65	—	—	7.45	—	—	
„ „	70.95	5.18	13.55	—	—	10.32	—	—	
„ „	66.86	4.81	11.74	—	—	16.59	—	—	
„ „	73.36	5.41	10.92	—	—	10.31	—	—	
„ „	68.39	5.06	12.55	—	—	14.00	—	—	
„ „	58.68	4.48	9.83	—	—	27.01	—	—	

ANALYSIS OF GERMAN COAL BY W. BAER.

Locality.	100 Parts of Dry Combustibles at 212° F. yield: Carbon.	Hydrogen.	Nitrogen.	Oxygen and Nitrogen.	Ash.	Water in Raw Combustibles.
SILESIA: —						
Pit, Kön. Louise, Pochhammer seam	77.25	4.98	—	13.86	3.91	3.32
„ „ Reden	82.72	5.05	—	10.67	1.56	3.00
„ Hoym	72.96	4.38	—	12.12	10.54	4.80
„ Graf Hochberg	70.87	5.63	—	14.35	9.15	3.64
„ Neue Heinrich	80.82	4.96	—	8.14	6.08	2.21
„ Fuchs	79.30	5 06	—	10.56	5.08	3.95
„ David	79.18	4.55	—	11.08	5.19	4.70
„ Segen Gottes	82.02	5.22	—	10 25	2.51	3.97
WESTPHALIA: —						
Zeche, Kunstwerk	89.58	4.30	—	4 04	2.08	1.29
„ Sabyer und Neuak	85.62	4.65	1 71	7.64	2.09	1.29
„ Hundsnacken	88.23	3.86	—	3.69	4.22	1.33
„ Victoria Matthias	86.43	5.32	—	5.67	2.58	1.66
SAXONY: —						
Zeche, Von Löbezün	81.88	3.68	—	3.65	10.79	0.71
„ „ Wettin	77.53	5.13	—	5.30	12.04	0.82
SAARBRÜCK: —						
Pit, Gerhardt, Benst seam	72.38	4.46	—	15.05	8.11	5.77
„ „ Heinrich seam	70.20	4.70	—	13.27	11.83	5.27
„ Duttweiler, Beyer „	81.29	5.30	—	8.54	4.87	2.24
„ „ Natzmer „	83.63	5.19	0.60	9.66	1.52	1.87
„ Heinitz, Blücher „	80.53	5.06	—	11.91	2.50	2.31
„ „ Aster „	78.97	5.10	—	13.22	2.71	2.45
DUREN: —						
Pit, Centrum, Gyr „	90.62	4.50	—	1.31	3.57	1.26
„ „ Fornegel „	84.06	4.27	—	2.22	9.45	1.21
„ „ Grosskohl „	83.69	4.07	1.25	8.25	3.99	0.97
„ James „ „	89.48	4 29	—	3.98	2.25	1.07
„ Ath, Grosslangenberg seam	90.41	4.03	—	4.11	1.45	1.50
„ Neulauerweg, Grossathwerk seam	89.32	3.80	—	2.71	4.17	1.48
„ „ Furth seam	88.59	4.10	—	4.39	2.92	1.31

ANALYSIS OF COAL FROM SARDINIA, BY ABBENE AND ROSSI.

Locality.	100 Parts of Dry Combustible contain: Carbon.	Hydrogen.	Oxygen.	Ash.
Canton Goneza	59.98	4.75	29.42	5.85

ANALYSIS OF COAL FROM TUSCANY, BY LA CAVA AND BUNSEN.

Locality.	100 Parts of Dry Coal — Contain: Carbon.	Hydrogen.	Nitrogen.	Oxygen.	Leave: Ash.	Coke.	By whom analysed.
Monte Massi (Tuscany)	62.00	5.00	0.92	17.83	14.25	56.5 to 57.6	La Cava
„ Bomboli	76.49	4.86	0.93	13.01	4.71	60.7 to 61.3	
„ Massi	73.63	5.28	17.89		3.20	—	Bunsen
„ „	74.00	4.20	17.00		4.10	—	

ANALYSIS OF COAL FROM SILESIA AND WESTPHALIA, BY W. BAER.

Locality.	Water per cent.	Percentage in Dry Fuel.			
		Carbon.	Hydrogen.	Oxygen and Nitrogen.	Ash.
SILESIA :—					
Leopold pit	3.55	76.21	5.03	13.50	5.26
Fausta pit, Clara seam	3.75	76.63	4.98	13.92	4.47
,, Fausta seam	3.84	77.25	4.58	13.35	4.82
König's pit, Gerhard seam	4.15	79.51	4.87	12.96	2.66
,, Heintzmann seam	4.37	73.48	4.95	18.64	2.93
Pit Morgenroth	8.35	74.57	4.82	16.14	4.47
,, Leo	4.06	78.22	4.89	12.95	3.94
,, Louise, upper seam	3.81	70.02	4.99	14.87	10.12
,, ,, lower ,,	3.27	70.79	5.32	19.34	4.55
,, Eugeniens Glück	6.83	73.20	4.93	19.11	2.76
,, Glückhilf	2.39	80.82	5.10	9.51	4.57
,, Königin Louise, Heinitz seam	3.35	73.91	4.85	17.59	3.65
WESTPHALIA :—					
Zeche Laura	1.05	74.81	4.35	8.76	12.08
,, Glücksburg, Franz seam	1.28	72.66	4.05	9.24	14.05
,, ,, Flottwell seam	1.08	77.25	4.02	8.14	10.59
,, der Engelsberg	1.23	85.90	4.56	6.33	3.21
,, Schafberg, Alexander seam	1.27	82.02	4.16	4.53	9.29
Tiefbau Franziska	1.19	77.10	4.55	11.79	6.56
,, Louise	2.25	78.05	5.05	12.92	3.98
Zeche Präsident	1.31	79.72	4.62	12.40	3.26
,, Friedrich Wilhelm	2.03	82.22	5.00	7.71	5.07
Coke, Fausta seam	4.96	87.82	1.43	5.14	5.61
,, Gerhard seam	5.88	90.01	1.46	6.30	2.23
Peat charcoal	5.28	78.42	4.01	14.77	2.80

ANALYSIS OF COALS FROM THE MINES OF HERACLEA—TURKEY.

Locality or Name of Mine.	Gaseous Constituents.	Ashes.	Fixed Carbon.	By whom analysed.
Armoredjik	31.00	5.00	64.00	Rivot
Zougoulaak	34.00	5.00	61.00	,,
Aladja-Aghry	45.00	4.00	51.00	,,
Silivria	49.50	7.00	43.50	Richardson
Rodosto, East of	48.00	12.00	40.00	,,
,, West of	48.00	5.00	47.00	,,
Erekli—Sea of Marmora	52.00	7.50	40.50	,,
Amasrah	40.00	6.00	54.00	Rivot
,,	37.60	10.40	52 00	,,
Djattae-Aghazy	27.60	11.40	61.00	,,
Near Heraclea	30.00	7.40	62.60	,,
,,	31.00	7.80	61.20	,,
Djaoucb-Aghazy	35.40	4.80	59.80	,,
Aladja-Aghazy	30.60	11.40	58.00	,,

COMPOSITION OF COAL FROM DISCO ISLAND, ARCTIC REGIONS, BY DR. FYFE.

Locality.	Specific Gravity.	Coke.		Volatile Matter.
		Carbon.	Ash.	
Disco Island	1.3848	39.56	9.84	50.60

ANALYSES OF COAL (BRITISH) BY BAER AND VAUX.

Locality.	100 Parts of Dry Combustible							Water per cent. at 110° C. in Raw Fuel.	Specific Gravity.	By whom analysed.
	Contain:					Leave:				
	Carbon.	Hydrogen.	Nitrogen.	Sulphur.	Oxygen.	Ash.	Coke.			
BRITISH :—										
Hawthorn, Hartley, Newcastle (caking)	76.87	4.99	—	11.99	—	6.15	—	1.2 to 0.850	—	Baer
Humricks, Stockton	86.86	5.00	—	7.36	—	0.78	—	0.990	—	Baer
Hawthorn, Hartley, Newcastle (caking)	93.04	0.26	—	1.61	—	5.09	—	—	—	Baer
Newcastle caking	81.41	5.83	2.05	0.75	7.90	2.07	66.70	1.355	1.2760	Vaux
Wigan cannel	80.07	5.53	2.12	1.50	8.09	2.70	60.36	0.906	1.2760	Vaux
St. Helens, Lancashire, Rushy park	75.80	5.21	1.92	0.90	11.89	5.17	65.00	3.232	1.2790	Vaux
Staffordshire, Wolverhampton	78.57	5.29	1.84	0.39	12.88	10.30	57.21	11.290	1.2785	Vaux
" "	—	—	—	2.57	—	3.01	58.20	8.390	1.2760	Vaux
Anthracite, Wales	90.39	3.28	0.83	0.91	2.97	1.61	92.10	2.000	1.3925	Vaux
Lignite, Bovey, Heathfield, Chudley, near Exeter	66.31	5.63	0.56	2.36	22.86	2.27	30.71	34.660	1.1290	Vaux
Turf	54.02	5.21	2.30	0.56	28.17	9.73	29.30	25.560	0.8495	Vaux
OREGON TERRITORY	—	—	—	—	—	35.49	66.50	5.624	1.5780	Vaux

COMPOSITION OF COAL ASHES.

—	St. Etienne (Berthier).	Cantyre (Thomas).	—	Elswick (Richardson).
Silica	—	45.5	Silica and alumina	90.08
Alumina, insoluble in acids	62	43.9	Oxide of iron	3.63
" soluble in acids	5		Lime	1.49
Lime	6	3.2	Magnesia	trace
Magnesia	8	3.3	Sulphate of lime	0.93
Oxide of magnesia	3		Potash	trace
Oxide and sulphuret of iron	16	1.4	Moisture	3.80
Sulphuric acid	—	1.7		
Chlorine	—	0.1		
Potash and soda	—	0.3		
	100	99.4		99.93

COMPOSITION OF THE ASHES OF PEAT, BY BERTHIER.

—	Château Landon.	Voitsumra.	Troyes.	Vassay.	Framont.
Gelatinous silica	15.0	Silica 36.5	—	—	40
Alumina	7.0	17.3	and oxide iron 14	—	30
Carbonate and caustic lime	63.0	—	—	Carbolate 51.5	
Oxide of iron	7.0	33.0	—	11.5	
Carbonate of potash	0.5				
Clay, insoluble in acid	7.5	—	and silica 26	11.0	
Zinc	—	2.0	23	—	30
Magnesia	—	3.5	14		
Sulphate of lime	—	4.5	—	26.0	
Muriate of lime	—	0.5			
Carbon	—	2.7	Carbonic acid and sulphur 23		
	100.0	100.0	100	100.0	100

COMPOSITION OF THE ASHES OF DIFFERENT VARIETIES OF COKE, BY GAULTIER.

Locality.	Sulphate of Lime.	Silica.	Alumina.	Carbonate of Lime.	Carbonate of Magnesia.	Oxide of Iron.	Oxide of Manganese.
ENGLISH:—							
Iron bridge	12.55	42.10	34.40	4.80	0.40	5.28	trace
Dudley	8.64	35.40	30.40	6.48	—	18.68	„
Merthyr Tydvil	4.56	41.60	35.44	6.46	1.08	10.80	„
ST. ETIENNE:—							
Puits St. Henri	2.40	73.20	14.40	0.80	0.70	7.98	„
„ du fils	2.40	54.90	37.00	3.20	—	2.30	„
„ de Carrode	4.90	56.50	23.00	0.40	0.76	14.38	„
„ Robert menu	5.60	44.50	34.34	7.00	0.50	7.18	„
„ dessus	2.20	50.00	32.00	1.40	0.70	13.28	„
„ des planches	3.60	43.50	36.20	6.20	0.50	9.42	„
„ de la grande fendue	3.50	58.20	34.00	0.30	0.30	3.32	„
RIVE-DE-GIER:—							
Puits de la grande Croix	3.20	55.00	19.80	8.80	—	13.00	„
„ des Combes	8.70	36.30	11.00	24.20	—	19.06	„
„ de St. Mathieu	4.90	55.00	22.24	5.50	8.80	3.32	„

ANALYSES OF BROWN COAL OR LIGNITE FROM PRUSSIAN SAXONY, BY F. BISCHOFF.

Locality.	Freshly Mixed Coal yielded:		Percentage in Dry Fuel:			
	Water per cent.	Specific Gravity.	Carbon.	Hydrogen.	Oxygen and Nitrogen.	Ash.
Riestedt, George Pit	33.40	1.197	57.13	4.16	27.05	11.66
„ „ fossil wood	31.70	1.218	61.13	5.09	31.95	1.83
Voigtstedt, earthy, with fossil wood	49.20	1.241	49.15	4.45	32.25	14.15
Löderburg „	49.50	1.219	45.30	4.90	31.95	7.85
Mertendorf „	48.60	1.233	49.45	5.17	24.84	21.54
Altenweddingen, earthy	47.30	1.194	57.71	4.75	22.94	14.60
Biere	46.90	1.200	55.92	4.77	22.48	16.83
Tollwitz, earthy	49.60	1.257	57.51	5.29	25.40	11.80
Pretzsch „	50.70	1.213	50.80	4.96	26.20	18.04
Teuditz „	48.60	1.263	54.02	5.28	27.90	12.80
Brumby „	40.60	1.263	47.78	4.28	18.42	29.52
Lebendorf „	42.70	1.318	47.73	4.34	17.64	30.29
Zscherben „	49.50	1.207	57.82	5.59	24.53	12.06
Runthal, upper seam, earthy	50.00	1.139	59.35	5.86	26.31	8.48
„ lower „ „	48.70	1.127	65.94	6.07	25.67	2.32
Würschen, earthy	49.90	1.142	60.76	5.99	23.13	10.12
Gorstewitz „	—	—	67.11	10.28	10.02	12.59
Rauen (Förderkohle)	14.83	—	59.00	4.55	25.77	10.68

ANALYSES OF AUSTRIAN LIGNITE, BY SCHRÖTTER.

Locality.	100 Parts of Dry Combustible						Specific Gravity.
	Contain:				Leave:		
	Carbon.	Hydrogen.	Sulphur.	Oxygen.	Coke.	Ash.	
Wildshut	53.79	4.26	0.98	25.39	15.58	54.7	1.306
Thallern	49.58	3.84	4.56	22.68	19.34	63.7	1.413
Glognitz	57.71	4.49	3.12	22.14	12.54	54.4	1.364
Pitch coal from Grünbach	69.66	4.29	1.71	17.42	6.92	60.9	1.320

ANALYSES OF GERMAN BROWN COAL OR LIGNITE, BY W. BAER.

Locality.	100 Parts of Combustible dried at 212° F. yielded: Carbon.	Hydrogen.	Oxygen and Nitrogen.	Ash.	Water per cent. in Raw Combustibles.
Rauen, in pieces (1)	61.38	4.91	23.57	10.14	38.66
,, ,, (2)	60.00	4.56	25.43	10.01	25.82
Frankfurt on-the-Oder	59.65	4.86	26.41	9.08	16.07
Tollwitz (1)	63.14	5.17	19.99	11.10	51.46
,, (2)	64.70	5.63	18.11	11.56	39.52
,, (3)	62.07	5.56	19.90	12.47	18.03
Zscherben	64.26	5.76	17.44	12.54	45.37
Biere	52.80	4.99	15.67	26.54	31.24
Stechall	64.53	5.17	25.35	4.95	43.67
Wittenberge	64.07	5.03	27.55	3.35	17.26

ANALYSES OF LIGNITE, CHIEFLY OF FRANCE, BY BERTHIER AND DUFRÉNOY.

Locality.	100 Parts of Combustible contain: Carbon.	Volatile Matter.	Ash.	By whom analysed.
Lignite du Val Pineau	36.5	57.0	6.5	Berthier
,, Gurdanne	41.8	43.0	15.2	
,, Fureau	36.0	53.0	11.0	
,, Saint Martin de Vaud	45.0	44.0	11.0	
,, Koep Fuarch	41.0	47.0	12.0	
,, Elbogen	24.0	69.3	6.7	
,, Alphie	27.5	56.5	16.0	
,, Triphilis	31.0	51.0	18.0	
,, Konnin	34.0	53.5	12.5	
,, Baffin's Bay	58.8	29.3 liquid + 16.7 gaseous	5.2	
Bituminous wood	44.1	37.1 liquid + 17.4 gaseous	1.4	
,, ,,	37.1	61.5	1.4	
Lignite Utweiller (Rhine)	67.3	31.8	0.9	
,, Germany	42.9	52.5	4.6	
,, Edon (Charente)	39.0	50.0	11.0	
,, St. Lon (Basses-Pyrénées)	48.4	46.0	5.6	
,, L'Enfant-dort (Bouches-du-Rhône)	49.3	46.8	3.9	
,, Minerve (Aude)	32.6	57.4	10.0	
,, Dauphin (Basses-Alpes)	43.6	49.0	7.4	
Jet Ste. Colombe	60.4	37.9	1.7	Dufrénoy
Lignite Marseilles	49.3	46.8	3.9	
,, Dauphiné	43.6	49.0	7.4	
Fossil wood	44.1	37.1 liquid + 17.4 gaseous	1.4	
Bituminous wood	38.4	39.3 liquid + 19.8 gaseous	2.5	
Cologne earth	37.4	31.3 liquid + 25.6 gaseous	5.7	

ANALYSES OF TURF FROM KAISERLAUTERN, NEAR HOMBERG, BY WALZ.

Locality.	100 Parts of Combustible dried at 212° F. yielded: Carbon.	Hydrogen.	Nitrogen.	Oxygen.	Ash.	Water per cent. in Natural Condition.
Mackobächer Moor	62.15	6.29	1.66	27.20	2.70	8.0
Steinwender	57.50	6.90	1.75	31.81	2.04	8.3
Neidermoor	47.90	5.80	—	42.80	3.50	8.0

ANALYSES OF TURF FROM GERMANY, BY JAECKEL.

Locality.	Undried Turf gave:		100 Parts of Dry Turf, Ash deducted, yielded:		
	Ash.	Water.	Carbon.	Hydrogen.	Nitrogen and Oxygen.
Havel Flat, near Berlin (1)	8.13	17.63	56.43	5 32	38.25
,, ,, (2)	5.33	19.32	53.51	5.90	40.59
,, ,, (3)	5.51	18.89	53.31	5.31	41.38
Linnum Moor	8.36	31.34	59.43	5.26	35.31
Friesack Moor	8.91	21.82			
Cassel	18.27	26.60			
Near Hamburg	1.89	18.83	57.12	5.32	37.56

ANALYSES OF TURF (CHIEFLY FRENCH), BY BERTHIER, DIDAY, AND SAUVAGES.

Locality.	Carbon.	Volatile Matters.		Ash.	Water.	By whom analysed.
		Liquid.	Gas.			
Demarary	23.5	36.7	22.5	17.3	—	Berthier
Château-Landon	26.0	31.0	28.0	15.0	—	
Clermont (Oise)	30.1	28.4	24.1	17.4	—	
Reims	34.7	39.9	18.6	6.8	—	
Voitsuma (Bavaria)	38.6	38.5	21.2	1.7	—	
Rue (Somme)	21.0	72.0		7.0	—	
New Abbeville (Somme)	23.0	72.2		4.8	—	
Velleron (Vaucleuse)	17.3	65.3		17.4	—	Diday
Sécheval (arrondissement Rocroy and Nêzières)	22.0	39.2		8.3	0.5	Sauvages

ANALYSIS OF FUEL FROM RUSSIA, BY VOSKRESSENSKY.

Variety of Fuel.	Locality.	Carbon.	Hydrogen.	Oxygen and Nitrogen.	Ash.
Anthracite	Gruschewskaja Stanitza (Don Cossacks)	93.785	1.732	2.940	1.543
,,	Lissitschja Balka	90.598	2.840	1.712	4.850
Coal	Solikamsk (Govt. Perm)	72.228	4.275	17.457	6.040
,,	Bachmut	71.173	4.977	21.502	2.348
,,	Charkow (near Petrowska Sloboda)	72.249	3.524	21.067	3.160
,,	Tschernolesnaja (Caucasian)	70.724	4.855	21.705	2.716
,,	Kaluga (near Selinina)	63.934	4.210	12.456	19.380
,,	Wladimir (on the Oka)	60.262	4.430	28.848	6.460
,,	Rjasan (on the Ranowa)	50.259	4.510	19.271	25.960
Brown coal	Tiflis	63.346	5.678	27.836	3.040
,,	Irkutsk (on the Argunia)	47.462	4.560	33.028	14.950
Bit. shale	Kurland (on the Windau)	20.600	2.750	19.730	56.920
Turf	St. Petersburg	39.084	3.788	51.088	6.040

APPENDIX.

ON THE GENERAL PRINCIPLES OF COAL WASHING.

By Mr. FREDERICK J. ROWAN, C.E.

Coal washing forms an increasingly important step in the preparation of the smaller varieties of coal for the market. For the manufacture of coke, where the coal is usually first reduced to powder, it is even more important.

Careful classification of the different kinds of small coal according to size receives great attention on the continent of Europe, but is generally neglected in this country by the majority of mine-owners, as was the case in France until recently, according to M. Callon's remarks in his "Lectures on Mining."* Where it is practised, however, it is found to be of great advantage, because there is a certain size or condition of coal which is the most suitable for different processes or operations, and sizing therefore enables the coal to be applied more easily and in the most suitable condition. In some parts of the Continent a higher price has been obtained for coal thus classified according to a suitable size than was previously paid for the same coal in a mixed state, having an average of larger pieces than was necessary for the purpose of the consumer. The large coal was thus set free for other purposes more suited to it. Hand-picking is generally resorted to in this country, and shaking or revolving screens are sparingly used in general. There is no doubt, however, that much of the hand labour could be replaced by mechanical methods which classify the coal more completely, at the same time treating it more gently, so that a smaller proportion of small coal and a less cost for sorting and handling result.

Washing machines are themselves classifiers according to size, besides being purifiers of coal from pyrites, shale, and earthy matters in general. Their use, with that of the other mechanical appliances for handling and sizing the coal, is regulated simply by the question of cost.

Comparing the treatment of ores and coal as regards the quantity and value of the products, M. Callon remarks:† "In the case of metallic ores, we have to operate upon small quantities of valuable substances, which admit of our having recourse to delicate contrivances and frequent repetitions of the same process, notwithstanding the amount of capital required and the high cost of labour entailed by it. In the case of coal, on the contrary, we are dealing with enormous masses of a substance of comparatively little value, the profit upon which is reduced to a minimum by competition.

* Delivered at the Ecole des Mines, Paris; translated by C. Le Neve Foster and W. Galloway (London, 1886).

† "Lectures on Mining," p. 144.

We are consequently forced to employ special machines, as simple as possible, acting automatically, as far as practicable, and capable of treating considerable quantities. We must generally abandon all idea of treating coal by frequent repetitions of the same process, or, at all events, do so sparingly, so as not to burden it with too heavy costs. And, finally, in planning the whole arrangement and the means of transport, we must have recourse to the best mechanical contrivances, so as to carry out the operations both with simplicity and economy."

It is not by any means a simple matter to select the best machinery for the treatment of a particular coal, because of the many varieties in the nature of coal and in the minerals mixed or associated with it, the differences in the manner and degree in which the foreign matters are mixed with it, the manner in which the coal breaks up, and all circumstances tending to produce varieties in the yield of ash in the large and small coal. Variations in washing machines, moreover, are needed according to the different sizes which it may be desired to treat in them; and the question of the amount of loss by the formation of mud or sludge has an important bearing on the means of treatment that are employed. These are all matters which demand experience in the treatment of different varieties of coal in order to their being properly dealt with, so that the interests of neither coal-master nor consumer shall be neglected, and it may safely be said that no general rule of treatment can be laid down, and no one form or arrangement of machines can be prescribed as suitable for all cases.

The process of coal washing, whatever may be the special machine employed, depends upon simple but very interesting principles, namely, the conditions which accompany or regulate the fall of solid matter in deep or shallow water.

It has been found that particles of different substances fall in a fluid at different speeds according to their densities and volumes or sizes. M. Callon* takes the case of a fluid, of a given density, at rest, in which a particle, having a certain specific gravity and section at right angles to the line of fall, is falling with a given velocity, and shows that three forces act upon the particle. These are, 1, gravity; 2, the thrust of the fluid; and 3, the resistance due to the viscosity of the fluid, which resistance is proportional to the surface of the body as well as to the square of the velocity. He examined the action algebraically and worked out the different effects due to shallow and deep fluids, arriving at the result that in a shallow fluid, or, in other words, at the very beginning of the fall, before there has been time for the velocity to become great, the motion takes place solely according to density. Consequently, "those machines which utilize only the first instants of the fall, will have a high effect as concentrators."

When the depth is sufficient for a regular state of affairs to become established, all particles having a like volume and specific gravity will have an equivalent rate of fall.

P. Von Rittinger† investigated the subject many years ago by means of numerous experiments, and found that in water the limiting velocities of particles of different diameters and different densities (that is, the velocities of descent in still water which they do not exceed, but which become uniform for each piece respectively, when space permits them to acquire those speeds) are quickly reached, small pieces of 1 millimetre diameter reaching it in under half a second, and large pieces of 16 millimetres diameter in less than one second.

The following table gives some of Rittinger's results which illustrate this point:—

* *Op. cit.*, p 47.

† *Lehrbuch der Aufbereitungskunde* (Berlin, 1867).

Nature of the Substance.	Specific Gravity.	Transverse Dimensions.	Values of the Velocity in				
			¼ Sec.	½ Sec.	¾ Sec.	1 Sec.	2 Sec.
		millim.	metre.	metre.	metre.	metre.	metre.
Galena	7.5	16	0.903	1.444	1.630	1.650	1.650
Pyrites	5.0	16	0.825	1.174	1.287	1.293	1.293
Quartz	2.6	16	0.570	0.767	0.801	0.817	0.817
Galena	7.5	4	0.704	0.814	0.823	0.824	0.824
Pyrites	5.0	4	0.586	0.643	0.646	0.646	0.646
Quartz	2.6	4	0.383	0.409	0.409	0.409	0.409
Galena	7.5	1	0.409	0.413	0.414	0.414	0.414
Pyrites	5.0	1	0.321	0.323	0.323	0.323	0.323
Quartz	2.6	1	0.203	0.204	0.204	0.204	0.204

From many experiments with different minerals, and from calculations, Rittinger deduced a general law for the velocity of any substance falling in still water. This he expressed by the formula :*—

Velocity in feet per second $= 1.28 \sqrt{D\,(d-1)}$, where

D = the diameter in inches of the holes in the riddle through which the substance has passed.

d = the density of the substance, or its specific gravity compared with water taken as unity.

1.28 is a constant which was gradually arrived at from experimental results (where the velocity is expressed in metres per second, and D is taken in metres, this constant is 2.44).

This general principle having been established for the case of substances falling through still water, it is found that it is applicable also to the varied conditions of an ascending regular current of water, a descending current, or a horizontal current.

If particles are subjected to the action of an ascending current, either the speed of the current may be equal to the limiting velocity of fall in still water—in which case the particles will remain stationary—or if the speed of the current be either greater or less than this, the particles will either rise or fall with a velocity due to the difference of speed. In a horizontal current, the particles will take a curved path, the shape of the curve depending upon the speed of the current and the density of the particles.

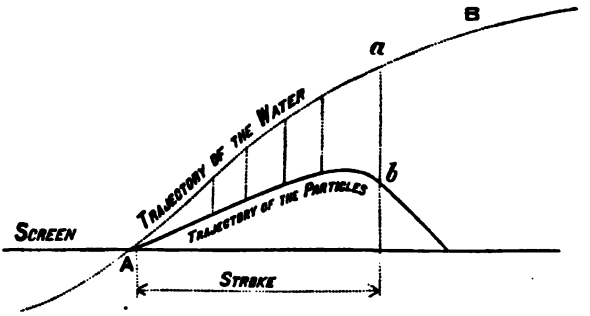
A very interesting diagram, showing graphically the trajectory of a particle of a mineral in relation to the trajectory of a particle of the water in a current, was communicated by M. Marsaut in the discussion on Mr. Harvey's paper on "Coal Washing" (in "Min. Proc. Inst. C.E.," vol. lxx., session 1881-82, part iv.), and may be taken as affording a useful graphic representation of these principles.

Figure 607 shows this diagram, regarding which M. Marsaut observed that "in effect, if the molecule of water and the particle first in contact left their trace on the drum of General Morin's well-known machine, the trajectory of the water would be a curve similar to AB, more or less approaching a sinusoid. The point A, where the screen had been shown, was that where the water had just the velocity limit of the particle in water and where consequently the water began to raise it. The particle rose in proportion to the velocity of the water, then stopped and retrograded as that velocity diminished. Hence it was evident that during the whole

* "Engineering," vol. xxix. p. 4.

evolution the particle of coal had continuously descended with respect to the particle of water, developing ordinates comprised between the two curves, such as *a b*, representing the path traversed."

FIG. 607.



It is evident that air may be taken as the fluid, instead of water, and, allowing for the difference in density and viscosity, we may apply the same general principles to the separation of mineral substances by means of currents of air.

The use of air has been carried out in pneumatic classifiers in America and in the air-jig of M. Krom, mentioned by M. Callon; but it is evident that it is suitable only for materials in a fine state of division—such as sand or finely ground ores—and that the currents of air must have a comparatively high velocity.

A mixture of air and water introduces a modified state of affairs not easy to follow unless the condition of the mixture and its average density were known.

If the water be broken up into a frothy state by the air, it is evident that the mixture will act as a fluid of less density than water but greater than air, and will not have the same effect upon large as upon small particles except at a higher speed of movement than water requires. If, however, the water remains sufficiently solid to allow the effect of its density to be felt by the mineral particles, then the air must act either in imparting a greater speed to the water, or in producing irregular pulsations in the movement of the particles of the minerals, according as they are immersed in water or in bubbles of air. Comparative practice will no doubt determine whether these effects are advantageous or not.

Experiments have been made by Dr. T. M. Brown* with a method of separating coal from its impurities by means of the employment of a liquid of greater specific gravity than coal but less than of slate, &c., associated with it. This liquid would have a greater density than water, and would allow all coal to float while the impurities alone sank: and this result would be arrived at without motion of the liquid being necessary. A liquid sufficiently cheap and readily obtainable was found in the solution of calcium chloride in water, and the results of experiments on a small scale were thoroughly satisfactory. These experiments illustrate effects of an opposite character to those produced by the use of air in coal washers, and they have a special interest on this account.

Before leaving this rapid sketch of general principles we may remark that Rittinger's fundamental law has shown the way to rules which should regulate the separation of coal by riddling, where this operation precedes

* "Trans. Amer. Inst. Min. Eng.," Philadelphia Meeting; "Jour. Iron and Steel Inst.," vol. ii. 1884, p. 700.

the "sorting by equivalence" of the operation of washing. M. Callon* has given the theoretical expression of these rules, and the application of Rittinger's method, which we quote, is taken from the digest of M. Marsaut's paper,† published in "Engineering." The determination of the limits of size within which preliminary riddling should be performed depends upon the density and consequent degree of impurity which may be taken as limiting the commercial value of the washed product.

The following table gives approximately the densities of pure coal and of the foreign substances associated with it, and the limiting velocities of pieces of different sizes as deduced from Rittinger's formula—

$$2.44\sqrt{D\,(d-1)}.$$

Materials in Pieces of Irregular Shapes.	Density.[1]		Limiting Velocity of Fall in Metres per Second.			
	d.	$(d-1)$.				
Coal, pure	1.3	0.3	0.267	0.231	0.189	0.134
„ shaly	1.6	0.6	0.378	0.327	0.267	0.189
„ more shaly	1.9	0.9	0.463	0.400	0.327	0.231
Shale, pure	2.2	1.2	0.535	0.463	0.378	0.267
„ with pyrites	3.4	2.4	0.756	0.654	0.535	0.378
Pyrites	5 0	4.0	0.976	0.844	0.691	0.488
Diameter of Holes in Riddle { Millimetres			40	30	20	10
{ Say inches			$1\frac{1}{2}$	$1\frac{1}{4}$	$\frac{3}{4}$	$\frac{3}{8}$

[1] The first column of density is the absolute density d, taking water = 1.0; the second is the excess $(d-1)$ above that of water.

"When coal becomes so shaly that its density rises to 1.6, it can scarcely be considered any longer capable of being used as fuel. If this, therefore, be assumed as the limit of density or impurity to be allowed in the washed product, it is evident that before washing the stuff which has passed through a mesh of 40 mm. ($1\frac{1}{2}$ inch), it should first be riddled again over a mesh of 20 mm. ($\frac{3}{4}$ inch) to separate all below this latter size. For it is seen from the above table that the 20 mm. shaly coal of 1.6 density falls through the water with the same velocity (0.267) as the 40 mm. pure coal of 1.3 density; consequently the 20 mm. shaly coal, together with all smaller stuff of great density, would fail to be separated from the 40 mm. pure coal by the washing." Similarly on this assumption with regard to density, any class of raw coal which had passed through one riddle should be riddled again over a sieve of half the previous mesh, thus:—

	mm.	mm.	mm.	mm.	mm.
From stuff which has already passed through a mesh of	40	30	20	10	5
Should be separated all that passes through a mesh of	20	15	10	5	$2\frac{1}{2}$

If, however, we wish to remove from the washed product merely the pure shale, having usually a density of 2.2, and all substances of greater density, a ratio of 4 to 1 for the preliminary riddlings would serve instead of the foregoing 2 to 1. Then—

	mm.	mm.	mm.	mm.	mm.
From stuff which has already passed through a mesh of	40	30	20	10	5
Should be separated all that passes through a mesh of	10	$7\frac{1}{2}$	5	$2\frac{1}{2}$	$1\frac{1}{4}$

Other data may be assumed, but these examples will serve to show how

* *Op. cit.*, pp. 51, 52.

† *Bulletin de la Soc. de l'Indus. Minérale*, 1879; "Min. Proc. Inst., C.E.," vol. lv. p. 259.

the preliminary riddling may be arranged to secure a given result in the washed product.

"If a lot of *unriddled* small coal, such say as would pass through a mesh having holes of 40 mm. (1½ inch) in diameter, were allowed to fall through a sufficient depth of water in any vessel, or were exposed long enough to the action of an ascending current of water, there would be formed in the vessel a series of horizontal layers, each composed of bits which had fallen through the water with the same velocity, and must necessarily be deposited at the same depth. Each thin layer thus deposited, with the exception only of the bottom one, would be made up of large bits of coal having the minimum density, of successively smaller pieces of less pure coal of greater density, and of shale and other impurities; the bits thus assorted being all of them equal in speed of falling, or equivalent to one another throughout each individual layer." Several classes of stuff thus sorted in water by the simultaneous agency of size and density, present a different result from that produced by classification effected according to size alone by ordinary riddles; and it is evident that each class of stuff thus forming a layer could have the pure coal separated from the foreign matters in the layer by being riddled through a suitable mesh. The riddling is, however, usually done first, because it is found that the washing is more perfectly carried out when the coal is sized before washing, so that each size can be washed separately. This is easily understood from the foregoing principles, and may be explained by considering the action of washing machines, as is done by Mr. R. de Soldenhoff,* and by the fact that obviously a mixture of pieces of coal, shale, &c., of similar size can be more readily separated in water, than a mixture containing several sizes; there being a greater difference in velocity of descent, for example, between a large piece of coal and a large piece of shale, than between the same piece of coal and a smaller piece of shale. The apparatus employed in various places for classifying the coal according to size before washing consists of fixed screens, shaking screens (including the Briart patent screens), revolving screens, reciprocating tables, and pointed boxes or "Spitzkästen," as they are called in Germany, where they were invented by Herr Rittinger.

The consideration of these appliances with a view to arriving at an estimate of their comparative value in the work of sizing would demand a separate study.

The different methods of washing which have been introduced, and in which the operation of the principles already mentioned may be witnessed, are extremely interesting, and demand separate and detailed description. We shall merely enumerate them in concluding these remarks.

The simplest and earliest form of washing apparatus is the open trough or sluice, which was no doubt borrowed from the practice in washing metalliferous ores. This form still survives in some places, and Rittinger's "Spitzkästen" may be classed as a modification of the trough, although they are used for a primary classification by size. Then we have the various types of piston "jigging" machines, in which the water is either forced up through a perforated bed or sieve by the strokes of the piston, with an intermittent ascending current, or is made alternately to ascend and descend through the bed on which the coal is placed. There are also machines having a continuous ascending current of water produced either by a column of water, with pulsations of a greater velocity given by a piston, or by a centrifugal or other pump.

Some machines having an alternate upward and downward movement of the water have a layer of felspar, or some suitable mineral, placed on the

* "Proc. S. Wales Inst. of Engineers," vol. xiv. p. 88, &c.

perforated plate or sieve, in order to develop the filtering action of the downward movement of the water. This improvement is due to Herr Lührig, who is acknowledged to be the leading authority in Germany on the subjects of coal and ore washing and classification.*

In addition to these, there are the machines of M. Evrard and M. Marsaut, which, although governed by the same fundamental principles, yet exhibit original and ingenious methods of applying their action.

In Evrard's machine, the coal first falls through a depth of still water on to a perforated plate carried on the head of a hydraulic ram. The water is made to descend and ascend in a few irregular pulsations, and when it is at the highest point the sieve with the coal is caused to ascend slowly through it, when each layer of material is successively removed by being pushed or sliced off into waggons by a horizontal hydraulic ram. In Marsaut's machine, the coal is tipped into a large basket or cage having a perforated bottom, attached to the end of the piston rod of an overhead hydraulic cylinder. This basket is made to take successive regular drops of a few inches in still water, and is then withdrawn, the charge being removed in layers, the sides of the cage separating into horizontal sections, like drawers, to permit of this operation. These machines deal with a considerable quantity—four or five tons—of coal at a time, which makes up for their not having a continuous action.

All good installations of washing plant demand, as accessories, means for properly drying, and for elevating and conveying the coal both before and after washing. Complete installations manipulate the coal automatically from the moment of its arrival from the pit hutches until the different sorts are delivered into the proper waggons or receptacles. Means are also provided for removing and depositing the shale and other rubbish separated from the coal by washing.

* See paper by Mr. C. P. Rathbone in "Trans. N. of England Inst. of Mining and Mechanical Engineers," vol. xxix., 1879-80; also Prof. Kreischer in *Jahrbuch für das Berg- und Hüttenwesen im Sachsen* for 1878.

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